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[656]

Competition by roads, waterways, and airways.

(Continuation) (1)

Great Britain.

By courtesy of the British Railway Clearing House, we publish hereafter a memorandum of the British Railway Companies showing developments in regard to competition and co-ordination between road and rail during the year 1938.

LEGISLATION.

Passenger traffic.

Passenger traffic by road services in Great Britain is regulated mainly by the Road Traffic Acts of 1930, 1934 and 1937. No amendments have been made in these Acts during the year 1938, but the following points in connection therewith are of interest :

Small operators.

As shewn by the figures in Table 1, the tendency for small operators to be absorbed by the larger concerns still continues.

TABLE 1.

At 31st December	Number of operators owning :			Total number of vehicles owned by		
	Up to 49 vehicles.	50 or more vehicles.	Total.			
	(1)	(2)	(3)	(1)	(2)	(3)
1933	5 814	112	5 926	18 329	27 064	45 393
1934	5 620	115	5 735	17 713	28 082	45 795
1935	5 186	114	5 300	16 976	29 461	46 437
1936	4 853	121	4 974	16 311	31 662	47 973
1937	4 648	129	4 777	16 010	33 564	49 574

(1) See *Bulletin of the Railway Congress*, June 1934 and subsequent numbers.

TABLE 2.

Year.	Stage services.		Express services, excursions and tours.		Contract carriages.		Total.	
	Vehicle-miles.	Ratio to 1934.	Vehicle-miles.	Ratio to 1934.	Vehicle-miles.	Ratio to 1934.	Vehicle-miles.	Ratio to 1934.
1934	1 202	100	92.5	100	51.4	100	1 346	100
1935	1 234	103	89.4	97	57.7	112	1 381	103
1936	1 278	106	88.7	96	64.0	125	1 431	106
1937	1 297	108	92.2	100	72.2	141	1 462	109

Road service licences for express carriages.

The period for which road service licences for express carriages were issued has now been increased from 1 to 3 years.

Types of passenger road services.

The measure of stability that has been achieved in the different classes of passenger transport under the 1930 Act is shewn clearly in the figures of the public service vehicle-miles (in millions) run in Great Britain during the last four years (Table 2).

Stage services (local and short-distance work, much of which is not competitive with rail) are increasing but slightly; express services and excursions (regular and seasonal long-distance work, directly competitive with rail) have not increased at all. The only unsatisfactory feature of the position from a railway point of view is the rapid growth in contract carriage work (private hire), owing to the less effective control by law of this branch of the industry.

Goods traffic.

Goods traffic by road services in Great Britain is regulated mainly by the Road and Rail Traffic Act, 1933, as amended by subsequent legislation. Table 3 hereafter shows that the Road and Rail Traffic Acts have operated so as effectively to check the increase in the number of vehicles operating under « A » (excluding Contract) and « B » licences, but there is a continued increase in the number of vehicles operating under « A » (Contract) and « C » licences.

TABLE 3. — **Number of motor vehicles authorised and in possession.**

Year.	« A » licences.	« A » contract licences.	« B » licences.	« C » licences.
1936	85 337	5 156	52 809	316 714
1937	83 626	7 475	53 775	362 380
1938	83 749	9 467	54 906	365 025

NOTE.

« A » Licences — Open. — Vehicles used by public carriers.

« A » Licences — Contract. — Vehicles used exclusively for the conveyance — under contract for a period of not less than

one year — of the traffic of a particular trader.

« *B* » *Licences.* — Vehicles used by persons who carry goods in connection with any trade or business of their own and also as public carriers. These licences may have attached to them conditions limiting conveyance for hire or reward to :

(*a*) A defined area or between specified places,

(*b*) Certain classes of goods only,

(*c*) Goods of specified persons.

« *C* » *Licences.* — Vehicles used by traders who carry goods in connection with their own business only.

« C » Licence applications are not opposable. It is difficult to estimate to what extent the increase in these vehicles means greater competition with the Railways.

Carriers' licences.

Power to extend the currency periods of carriers' licences was contained in the Road Traffic Act, 1937. In August last, the Minister of Transport prescribed that these periods may, in future, be extended as follows :

« A » Licences — From 2 to 5 years;
« B » Licences — From 1 to 2 years;
« C » Licences — From 3 to 5 years.

The Licensing Authorities are empowered to grant, in certain circumstances, licences for shortened periods.

Bu Regulation dated September, 1938, the Minister doubled the cost of « A » and « C » licences; « B » licence fees were increased by 75 per cent. Carriers' licences still cost only a few pence a week.

Enforcement of road traffic law.

Prior to the issue of the Regulations extending the currency of the licences, the Traffic Advisory Council, in recommending these increased periods, urged that the observance of the requirements of the Road Traffic Law which is a condition of the grant of every licence should be upheld by the strongest possible measures, including, after fair warning, suspension and revocation of licences. The Minister has asked the Transport Advisory Council to consider the effect upon the well-being and economic position of the road haulage industry of the prevalence of breaches of the Statutes and Regulations relating to the operation of goods vehicles, in particular, excessive hours of work and driving, the use of unauthorised vehicles and of vehicles in contravention of the conditions attached to the licence, and to make recommendations as to the steps which should be taken to secure more general observance of the law in these matters. Investigations in regard to this question are proceeding.

Loading of vehicles.

The existing law in regard to the overloading of vehicles is unsatisfactory inasmuch as the legally permissible load does not necessarily bear any relation to the pay load for which the vehicle has been designed. In an endeavour to overcome this state of affairs the Minister of Transport has under consideration the question of regulations relating to the compulsory plating of goods vehicles with the maximum laden weight.

Wages.

The Road Haulage Wages Act, 1938, has been passed. The Minister of Labour is empowered to set up central and area boards in Great Britain to regulate the remuneration of road haulage workers

employed in connection with goods vehicles operating under « A » and « B » licences. Questions of unfair wages of drivers of « C » licensed vehicles may be referred to the Industrial Court. When the provisions of the Act are fully operative, it may be expected that some relief in competition from road operators who have paid their drivers inadequately may be obtained.

The Act exempts railway companies' staff by reason of the fact that adequate machinery already exists for railway employees.

Finance Act, 1938.

The Finance Act, 1938, authorised the customs duty on petrol and heavy oil for use by compression-ignition motor vehicles to be increased from 8 d. per gallon to 9 d. per gallon as from 26th April, 1938.

So far as petrol is concerned, this is the first increase in duty since 1931, although with regard to heavy oil, as mentioned in our 1935 report, this was increased from 1d. to 8 d. in 1935, placing both petrol-driven and heavy oil vehicles on equal footing.

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MEASURES TAKEN BY THE RAILWAYS THEMSELVES TO COMBAT ROAD COMPETITION.

Electrification.

Further extensions have been made in the electrification of the British Main-Line Railways during the past year, and the total mileage at the end of 1938 was 2 073 electrified track-miles. This mileage does not include services solely operated by the London Passenger Transport Board.

Further electrification extension schemes are in progress.

Train and rolling stock.

New rolling stock embodying the most up-to-date improvements was introduced on a number of the main-line expresses during the year, in addition to which a large number of the latest type of corridor coaches including buffet cars has been introduced in connection with the extension of the electrification mileage.

Railway Companies' cartage facilities.

The steps taken by the Railway Companies to combat road competition by extending their own cartage facilities are illustrated by the number of road motor vehicles operated by them in recent years. They are as follows :

At 31st. December	*Total.*
1934	7 651
1935	8 322
1936	9 068
1937	9 773
1938	10 339

The progressive increase shewn by these figures illustrates a steady improvement in the town and country cartage facilities offered by the Railway Companies.

Agreed charges.

At 2nd December, 1938, there were 776 agreed charges in operation approved by the Railway Rates Tribunal, as compared with 564 at 2nd December, 1937.

In addition, at 2nd December, 1938, 144 agreed charge offers had been accepted by traders and were awaiting the approval of the Tribunal.

The agreed charges in operation at the end of Septmeber, 1938, altogether accounted for 3.98 per cent. of the total revenue from parcels and goods train traffic.

Additions to the British Railways' stock of freight vehicles fitted with an automatic air-operated brake.

The particulars in Table 4 indicate the increase in the number of wagons fitted with an automatic air-operated brake excluding mineral wagons and brake vans) for the years 1932 to 1937 inclusive.

TABLE 4.

Number of wagons (excluding mineral wagons and brake vans) fitted with an automatic air-operated brake.						Percentage increase, 1937 over 1932.
1932	1933	1934	1935	1936	1937	
49 827	53 548	60 253	71 755	80 181 (*)	85 495	71.6

Railway rates and road competition.

As related in the 1937 report, the Transport Advisory Council, in their report upon service and rates, recommended in July, 1937, certain steps towards the creation of a system of rates for the road haulage industry. The position in the road haulage industry has not yet progressed sufficiently to enable Parliament to implement the Committee's report. In November, 1938, therefore, the Railway Companies approached the Minister of Transport with a view to obtaining relief from the regulations by which the railways are bound, in connection with the charges which they may levy for merchandise traffic. The question has been referred by the Minister to the Transport Advisory Council for its early consideration, and is at present under discussion by the Council with the interests concerned.

(*) Amended figure.

[621. 131]

The gain in power of streamlined locomotives,

by Prof. Dr.-Ing h. e. H. NORDMANN, Direktor bei der Reichsbahn, Berlin.

(Zeitschrift des Vereines Deutscher Ingenieure).

The gain in power by completely streamlining a 4-6-2 express locomotive is very high in relation to a standard non-streamlined type; with the design of streamline casing employed by the German State Railways, the increase, at the speed of 140 km. (87 miles) per hour, reaches, in the case of the locomotive of Class 03, the figure of 385 H. P. *e*, and is therefore, in practice of about 400 H. P. The regular realisation of this economy, in service, corresponds, in a more or less satisfactory degree, to the trials made with models in the wind tunnel; a more precise comparison of the trials with full-sized locomotives and model locomotives in the wind tunnel, will necessitate further tests being carried out.

Express locomotives fitted with a streamline casing, though they have only been in vogue for a few years, have ceased to be some kind of eighth wonder of the world. It may be said that they are now looked upon as forming an integral part of the motive power of the principal railway companies, although their present limited numbers hardly justify such a point of view. The explanation for this, apart from the fact that attention is always strongly riveted on innovations, is undoubtedly two-fold, namely, on the one hand, that streamlined locomotives or streamlined trains are used for working certain very fast regular services, and, on the other hand, that streamlined locomotives are the result of reasoning, and by this we mean that they represent the application to rail vehicles of the law relative to air resistance varying as the shape, as against the old formulæ which expressed the resistance solely in terms of the speel and weight.

But the qualitative gain in drawbar-horsepower, obtained by a shape favouring the air flow is not yet of such a nature as to satisfy us. The final objective in these researches can only be seen when the following two questions have been solved :

(1) What is, in terms of the speed, the extent of the gain in power or in tractive effort of a streamline locomotive as compared with a standard non-streamline locomotive of the same type ?

and

(2) To precisely what degree do the results obtained with full-size locomotives agree with those obtained during trials previously carried out on models in the wind tunnel ?

We are as yet only reaching out towards this final objective; the considerations set out below are intended to constitute an important step in this direction. It is, moreover, probable, for reasons we shall examine later, that an *absolutely* incontestable numerical solution is impossible.

If we consult what has been written with regard to streamline vehicles, we shall find that the American publications (1) give the impression of considerable publicity having been made in favour of this method of construction. This remark applies particularly to the best known American streamline steam-

(1) *Railway Age*, Vol. 98 (1935), pp. 719 and 865.

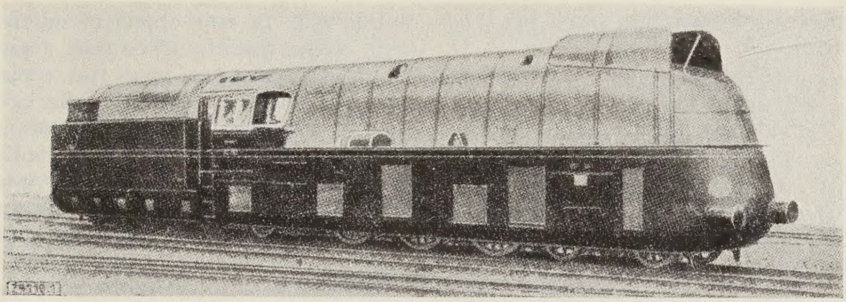


Fig. 1. — German State Railways 4-6-2 express locomotive No. 03.193 with streamlined casing.

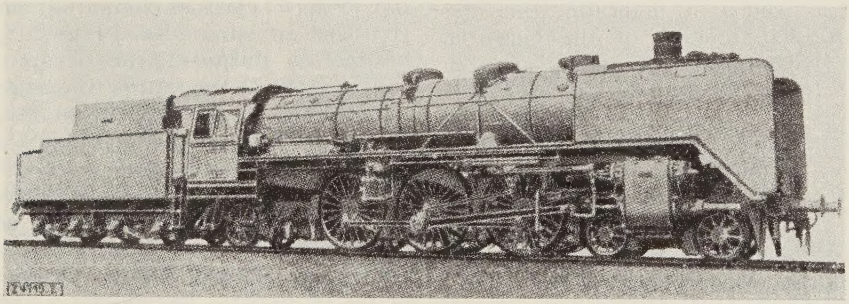


Fig. 2. — German State Railways standard type 4-6-2 express locomotive, class 03.

hauled train, called « The Hiawatha » (2); the press boasts of the eagerness with which the seats therein offered are taken up by the public, and continues the propaganda on behalf of this train by describing the improved coaches, and by stressing the greater degree of comfort thus afforded to passengers. But no mention is made of results of trials of a scientific nature which may have been carried out. Several descriptions are to be found in English journals of test runs with the « Silver Jubilee » train, culled from papers read by leading locomotive engineers (3), and there is no lack of information with regard to the powers developed and speeds attained. Nevertheless, the impression left by the descriptions given of such train runs is more sporting than scientific. Up to the present, German and French publications alone have tried to bottom the question. Mr. Parmantier has already examined the gain in power, obtained from a road trial with an old 4-4-2 express streamlined locomotive of the Paris-Lyon-Méditerranée Railways, as compared with its unmodified sister engine (4), as well as the economy in energy for hauling the train made up of four special coaches, which, with the locomotive, constituted an invariable make-

(2) See also P. H. BANGERT, *Z. VDI.*, Vol. 81 (1937), p. 510.

(3) Sir Nigel GRESLEY, *Modern Transport*, Vol. 36 (1936), No. 920, p. 7.

(4) A. PARMANTIER, *Revue Générale des Chemins de fer*, 2nd half-year, 1935, p. 373.

up, similar to the German *Henschel-Wegmann* train (5).

As regards the trials which have been carried out up to date in Germany, reference should be made to the articles we have already published on this subject (6). Information is therein given with regard to the gain in power obtained as compared with the standard type, as the result of the *partial* streamlining of a standard Class 03 express locomotive, the real object of this conversion being to ascertain if the behaviour of the axle and rod bearings was less satisfactory when covered up by the streamline casing, as well as to determine the total mechanical efficiency of the large 05 Borsig streamlined locomotives and the Henschel tank locomotive No. 61. This trial was carried through very successfully as regards the question of the bearings, but obviously had to remain incomplete from the air resistance point of view.

The efficiencies (this expression being used in the sense which is usual for locomotives, viz., the ratio of the drawbar H. P. to the indicated H. P.) shewed themselves to be of a high order for the 05 and 61 locomotives; that for the 05 locomotive was, for a speed higher by 40 km. (25 miles) per hour, almost exactly the same as the efficiency of the 03 locomotive. However, that, as we ourselves stated at the time, is only a conclusion obtained by deduction, because the 05 locomotive is appreciably bigger than the 03 locomotive, and consequently the gain in power due to the streamlining alone cannot be deduced from this result. But the construction of a 05 or 61 non-streamlined locomotive, built with the sole object of determining this gain, would, of course, have been too costly, the more so as the streamlined casing would have had to be provided for in the designs, and its subsequent addition to a locomotive, originally non-streamlined, would not have consisted merely in the addition of streamline casing plates, but would have meant a partial reconstruction.

Before going any further, it is necessary to give an answer to the first question laid down above, namely : — What is the gain in power of a German State Railway express streamlined locomotive of the 03 class, as compared with the standard non-streamlined type ? For investigation purposes, the German State Railways built the 03.193 (Borsig) locomotive, fig. 1, streamlined in the same way as the larger 05 locomotive; figure 2 shews the standard type by way of comparison. It was therefore no longer necessary to build the partner of the streamline locomotive. Moreover, the results were already known of the trials of the 03 express locomotive which had undergone the longest and most meticulous tests amongst German locomotives. As other urgent trials were in hand, it was not possible to couple the streamlined 03.193 locomotive to the dynamometer car immediately after its completion, and therefore, in the meantime, it was put on the extremely hard work of hauling the high-speed trains 23/24 on the Berlin-Hamburg line, where it attracted attention owing to its exceptionally low coal consumption, and scientific tests were awaited with much curiosity. However, this period of waiting also came to an end, and we are now going to deal with the comparative results.

Trials of full-sized locomotives.

Elements of comparison.

The trial runs of the 03.193 locomotive were carried out by the Grunewald locomotive testing staff, towards the end of 1936, on the Berlin-Magdeburg and Ber-

(5) Cf. Fr. BODEN, *Z. VDI.*, vol. 79 (1935), p. 1467, particularly p. 1470.

(6) H. NORDMANN, *Z. VDI.*, vol. 79 (1935), p. 1226; *Glasers Annalen*, vol. 117 (1935), p. 172; *Verkehrstechnische Woche*, 30th year (1936), p. 546.

See also *Bulletin of the Railway Congress*, July 1935, p. 857.

lin-Hamburg lines. Bearing in mind the principle that streamlining only has advantages for fast running, the speeds were limited to 100, 120, and 140 km. (62, 75 and 87 miles) per hour. Up to the speeds of 120 km. per hour, the usual test method was employed (7), with dynamometer car and brake locomotive, but at 140 km. per hour, the load hauled behind the dynamometer car had to be made up of corridor coaches, as the brake locomotive, an old S. 10, was no longer suitable for this speed. The test equipment consisted of the indicators fitted on the locomotive, the dynamometer for measuring the tractive effort, with a work integrating indicator (planimeter), speed indicator, and clockwork in the test coach, besides the water meter (also registering in the test coach) fitted on the boiler feed water pipes. This equipment was used for measuring the different test speeds, indicated and effective powers and tractive efforts (in the cylinders and at the drawbar), always over rather long sections run under working conditions, where, consequently, not only is the speed maintained practically uniform, but also the admission, and with it, the work done by the boiler. This latter is expressed by the evaporation per square metre of heating surface per hour — hence the necessity for measuring the feed water — and its most important value is the usual maximum steam production of the heating surface [57 kgr. per sq. m. (11.67 lb. per sq. ft.) per hour].

The reason why it is necessary to take into account the degree to which the boiler was worked is as follows : The *total* resistance of the locomotive, W_{loc}, is very simply obtained by deducting the effective tractive effort (Z) from the indicated tractive effort (Z_i), so that we have :

$$W_{loc} = Z_i - Z_e.$$

This resistance is composed, without it being possible to distinguish its different constituent elements, of the friction offered by the axlebox brasses and the friction from the rolling of the wheels, the resistance of the motion of the steam engine, and the air resistance. We are concerned here with this latter (the air resistance) or rather with the diminution of it by the streamline profile. Now, in the case of two identical locomotives, only differing by the streamlining, we get, with u representing the values of the non-streamlined locomotive and v representing those of the streamlined locomotive :

$$W_u = Z_{iu} - Z_{eu};$$
$$W_v = Z_{iv} - Z_{ev}.$$

As the two locomotives are assumed to be of the same type, we may, in the first place, admit that the friction from the axlebox brasses and the rolling friction are the same in both cases. As regards the friction from the motion, its value is not constant, but variable, since the friction from the gudgeon pins and crossheads increases with the speed. It is therefore only at equal speeds that we can neglect not only the rolling friction but also the motion friction, and it is only in this case that $W_u - W_v$ expresses the diminution sought in the air resistance, and, consequently, at the same time, the economic gain in the tractive effort $Z_{eu} - Z_{ev}$. As a matter of fact, it is only under these conditions, even with boilers and steam engines which are in other respects identical, that it is possible on the other hand, to admit the equality of the indicated tractive efforts Z_{iu} and Z_{iv}. Of course, we could take as a basis *any one* degree of boiler working, provided that it is the same; we should obviously still find the same advantage from the streamlining point of view. But the adop-

(7) K. Günther and Solveen, *Glasers Annalen*, vol. 108 (1931), p. 46, particularly pp. 52 et seq.; H. Nordmann, *Glasers Annalen*, vol. 121 (1937), particularly pp. 5 et seq.

tion of the usual maximum boiler working as the normal value is to be all the more recommended, as the choice of an excellent test value, as this maximum work also serves as a basis for arranging the timings.

Why then this prudent mode of expression, if the resistances due to the rolling friction, as well as the indicated tractive efforts, and consequently the powers, are the same ? In the first place, as a matter of fact, the resistances due to rolling friction are not exactly equal, because the streamlined locomotive and its tender are, of course, heavier than the non-streamlined locomotive and tender, the difference being due to the weight of the streamline casing plates and their fastenings; now the resistances due to friction vary with the weight. The case of the tender is even a little more complicated. The locomotive 03 is generally equipped with the usual 32 m³ (7 040 Br. gall.) tender, which would already have its weight increased by the streamline casing (and by the coal pusher under the tender canopy, fitted to facilitate the work of the fireman). But as a streamlined 37-m³ (8 140 Br. gall.) tender had already been designed for the locomotive 05, the locomotive 03.193 was also provided with a « 05 » tender in order to avoid introducing a new type of tender. We shall determine the correcting factor, which will however be small, necessary for compensation of the weights, when we proceed to make a strict comparison from the streamlining point of view, with the trial made with a model; but when comparing the powers, we shall consider the increase due to the streamlining and to the larger dimensions of the tender, as inevitable or as justified for service reasons. To be strictly accurate, the small extra tractive effort necessitated by the increased weight also entails a slight increase in the internal friction offered by the locomotive, but this value may be neglected as representing, so to speak, an infinitely small value of secondary importance.

But why are the tractive and indicated efforts and powers not exactly equal, seeing that the same boilers worked under the same conditions undoubtedly produce exactly equal quantities of steam per hour ? The reason lies in the extra heat conserving effect afforded to the steam cylinders underneath the streamline casing, the result of which is to produce a slight heat gain in the cylinders. According to figures 3 and 4, which embody the principal results of the Grune-

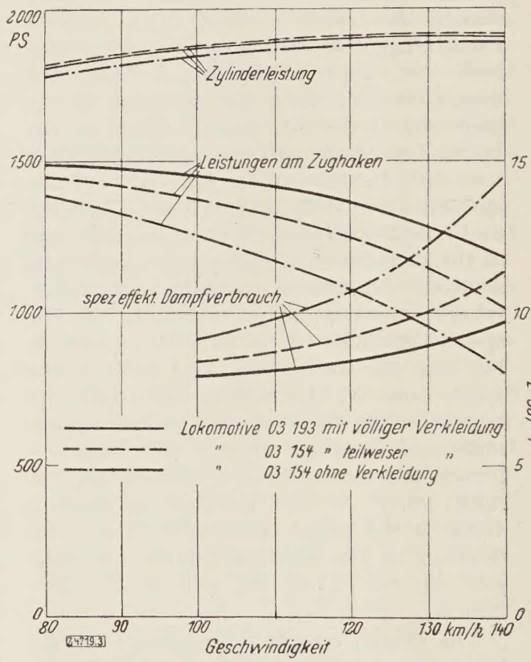


Fig. 3. — Comparative powers of the German State Railways 03 locomotive when completely, partially, and not streamlined.

Explanation of German terms :

Zylinderleistung = indicated power. — Leistungen am Zughaken = drawbar powers. — Spez. eff. Dampfverbrauch = specific effective steam consumption. — Mit völliger (teilweiser) Verkleidung = with complete (partial) streamlining. — Ohne Verkleidung = without streamlining. — Kg/PS$_e$ h = Kgr. per effective H. P./hour. — Geschwindigkeit = speed.

wald trials, this power gain is, approximately :

at 100 km. (62 miles) per hour, 25 I.H.P.;
at 120 km. (75 miles) per hour, 22 I.H.P.;
at 140 km. (87 miles) per hour, 20 I.H.P.;

as compared with the non-streamlined locomotive 03.154. With regard to this latter, which had been partially streamlined at a previous date, we had already

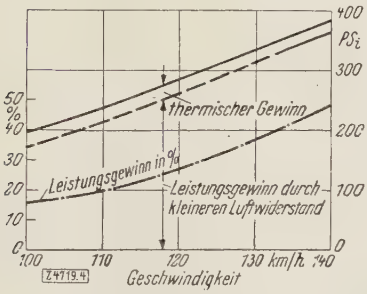


Fig. 4. — Gain in power due to complete streamlining.

Explanation of German terms:

Thermischen Gewinn = thermal gain. — Leistungsgewinn durch kleineren Luftwiderstand = gain in power due to the reduction in the air resistance. — PSi = I. H. P.

ascertained a thermal gain which was a little higher still [8]; this difference may be explained, partly by tolerances allowed in the measurements, and partly by the different diffusion of the air-streams. For the superiority in the drawbar power of the streamlined locomotive, we shall naturally have to take this indirect thermal advantage into account, whilst, for the purely aerodynamic comparison, it will be necessary to deduct it, as will be shewn later.

The approximate character of the test results.

We have stated above that results completely beyond dispute cannot be obtained; we shall give the reason for this. The dynamic pressure of the air, which is one of the principal factors in the air resistance, varies with the density of the air, and this latter varies with the barometer reading and the temperature. In connection with the trials of non-streamlined and streamlined locomotives, it is only if the density of the air had been the same for all the speeds, that the results woud be strictly comparable. It is easy to understand that this condition cannot be obtained when carrying out trials, because the atmospheric conditions, and often even the seasonal differences when the trials are carried out, are beyond control, to say nothing of the variable direction and force of the wind. We should obviously set aside the results of trials carried out during a storm, but we are obliged to take the less violent winds as they occur. This fact in itself involves no disadvantage, because perfectly calm weather is very rare, but it affects the apparent accuracy of the difference between the air resistances, seeing that here also it is impossible, for locomotive trial purposes, to realise identical conditions by artificial means. Even in the case of one and the same locomotive, the W_{loc} curve would only have a strictly correct aspect if the conditions had been the same as regards the wind, at the speeds of 100, 120, and 140 km. per hour.

A last fact which does not permit the results otbained to be freed from their approximate character lies in a certain divergence between the values of W_{loc} for the two non-streamlined 03 locomotives, running at high speeds. One of them was the strictly standard 03.109 locomotive, the first to be tested methodically at 140 km. (87 miles) per hour, and the other the aforementioned 03.154 locomotive, partly streamlined previously and fitted, in particular, with large side plates, these side plates being subsequently removed, as well as a part of the prominently domed plating on the smokebox door, or the smoke screens. The 03.109 locomotive registered the highest values for W_{loc}, particularly at the

(8) H. NORDMANN, *Z. VDI.*, vol. 79 (1935), p. 1226, particularly p. 1227.

speed of 140 km. 87 miles) per hour, but at maximum boiler capacity is developed a slight excess (not elucidated) in the indicated power as compared with the 03.154 locomotive [9]. With the indicated power, and consequently also the indicated tractive effort manifestly a little too high — the case of the completely streamlined 03.193 locomotive confirms this supposition — the resistance $Z_i - Z_e$ then assumed a little too high value, because the hydraulic dynamometer, employed as the indicating apparatus, in a manner of speaking, dynamically insensitive for Z_e may be considered as giving reliable indications between narrow tolerances. With regard to the 03.154 locomotive, this only retained, after all the other streamlining elements had been removed, a driver's cab of decreased width, i. e., an element which, according to the tests carried out in the wind tunnel at Göttingen, It is therefore possible that the value of W_{loc} for the non-streamlined 03.154 locomotive may be a little too low. Nevertheless, we have chosen it out of prudence as the guiding value of the non-streamlined locomotive, in order to avoid any exaggeration of the importance of the streamline casing. An unlooked for gain would, at any rate, be preferable to a deception. The tractive effort gains found :

$$Z_+ = (Z_i - Z_e)_u - (Z_i - Z_e)_v$$

and the corresponding powers $N = ZV/270$ (Z = tractive effort in kgr., V = speed in km. per hour) may therefore be considered as minimum values, all the more so as locomotive 03.154 was tested from the end of August to the middle of September, 1934, and the 03.193 locomotive in October and November, 1936, viz : in slightly cooler weather, and a slightly stronger head of air.

TABLE I. — **Gain in power at the drawbar by complete streamlining.**

Locomotive.			100 km. (62 mil.).	120 km. (75 mil.).	140 km. (87 mil.).
03.193. streamlined.	Effective power at the drawbar.	H.P.	1455	1365	1185
03.154. not streamlined.		H.P.	1260	1075	800
...	Power gains over the non-streamlined locomotive.	H.P.	195	290	385
		%	15.5	27.0	48.2

enabled, at least with an axial air-stream, (the oblique air-stream had not been applied at the time to this variation in shape), a slight advantage to be looked for as compared with the standard type.

(9) No one other than the central locomotive test department (with its facilities for comparison and verification) can have a better knowledge of the difficulties met with in the operation of taking indicator diagrams on high-speed locomotives. In isolated tests, the tolerances laid down for the indicator measurements are not often discernible.

Results obtained with the 03 streamlined locomotive.

After showing their approximate nature, let us now pass to the results themselves. Table 1 shews in the first place the superiority in power of the 03.193 completely streamlined locomotive over the 03.154 non-streamlined locomotive. Obviously this table tallies with the test results reproduced in figure 3.

The high order of these results will certainly surprise many readers; nevertheless — and that is precisely why we

have stressed previously in this article the reliable nature of the method of comparison — they cannot be doubted. They mean that : The gain in power at the drawbar by the application of the German State Railway type of complete streamlining to a 4-6-2 express locomotive, increases with the speed, and is notably very great at high speeds. At 140 km. (87 miles) per hour, it reaches a figure which is little lower than 400 H.P., viz : 385 H.P., or, in other words, 48 % of the power at the drawbar of the 03 non-streamlined locomotive [10].

Practical application.

The advantage conferred by streamlining from the service point of view is of course considerable. Notwithstanding this, it should not be the desire immediately to go so far as to convert every power gain into an increase in the load hauled, corresponding, in the range of 100 to 140 km. per hour, to two all-steel riveted coaches, with smooth elliptical roofs, weighing, with the passengers, approximately 50 tons. As a matter of fact, in this case, at the high speeds, the streamlined locomotive could not — the amount of work being equal — develop greater accelerating tractive efforts than the non-streamlined locomotive; and as these efforts would be exerted on a train 100 tons heavier, the accelerations required, both towards the end of the starting period and after all slowing-down periods, would be less. Besides this, as in the lower speed ranges, for example, at the start — wherein the excess of power due to the streamlined casing always becomes small, to disappear completely during very slow running (starting period) — the accelerations of the train weighing 100 tons more also diminish, the addition of two heavy corridor coaches of the 1928 type, would, to a certain extent, adversely affect the timings. Similarly, with the new welded corridor coaches, weighing approximately 40 tons the increase in the acceleration efforts would be too small for the timing of the train weighing 80 tons more not to become a little worse than that of the lighter train, with a non-streamlined locomotive. On the contrary, with a *single* corridor coach more - which already often forms a very welcome addition on trains enjoying public favour, such, for example, as the FD (long-distance corridor) trains — at about 100 to 140 km. per hour, the work demanded of the boiler being equal - we should have at our disposal an increase in accelerating or compensating power of approximately 100 H.P., rising up to 200 H.P. The initial acceleration would be a little less rapid, but at least there would be nothing to fear in the way of an adverse effect on the timing of the train, which, whilst affording a larger number of seats, might in fact be given a slightly better timing, with the proviso that a few actual runs would have to be specially considered.

If, on the contrary, the weight of the train is maintained at its old figure, the initial acceleration is not worse; while in the range of the high speeds, from 100 to 140 km. per hour, the whole of the 195 to 385 H.P. shewn in Table 1 is available for extra increases in accelerating and compensating power. Hence the train is not only better accelerated, but it also reaches a higher working (maximum) speed. Consequently, the streamlined locomotive then enables appreciably improved timings to be arranged. And if, finally, besides the weight of the train, the maximum speeds of the non-streamlined locomotive are retained, there will be a power saving of 195 to 385 H.P., with a corresponding saving in coal. As a matter of fact, the 03.193 locomotive, which, for twelve months worked express services on the German State Railways'

(10) A. Parmantier found 285 H.P. for his streamlined 4-4-2 locomotive, at 140 km. (87 miles) per hour; *Revue Générale des Chemins de fer*, 2nd half-year, 1935, p. 373, particularly fig. 10, p. 382.

Hamburg Division, according to whether the engine-miles or the ton-miles are taken as a basis, consumed 11.7 % and 15.2 % less coal than the standard locomotive. It is to be noted that for getting up steam, and in the lower speed ranges, the fuel consumption is the same. In the case of higher maximum speeds, which however are not to be considered for the 03 class, it goes without saying that the gain in power increases.

Formulæ summing up the trial results.

We have emphasized, on several occasions, whilst studying locomotive trials, that, as with exact physical sciences, the results of carefully conducted trials constitute the positive element, and that formulæ must only be established when they numerically express the trials with sufficient accuracy. Here the temptation might be to translate the results by a formula because the air resistances, and consequently also the differences in these resistances, vary as the square of the speed, and therefore the corresponding power economies $N+$ must be cubic functions (11). We should therefore write down, for example (on account of the convenience of the coefficient) :

$$N_{+} = k \left(\frac{V}{10}\right)^3.$$

Now this expression is, of course, only applied to the purely aerodynamic economy, whilst the measured power economies include the thermal gain mentioned above and the weight difference. We shall therefore not expect to find a series of strictly cubic functions expressing the power economies; nevertheless, it is surprising to find to what extent the agreement between the values of k corresponding to the speeds of 100, 120, and 140 km. per hour is unsatisfactory when numerical values are introduced (12); in fact, they drop from 0.195 to 0.140.

We pass now to the tractive efforts, which are simply deduced from the measured effective power, by means of the expression :

$$Z = \frac{270\ N}{V}$$

They are represented in figure 5 as being the difference between Z_i and Z_e. For the formation of new differences, we shall have recourse to the expression :

$$Z_{+} = (Z_i - Z_e)_u - (Z_i - Z_e)_v.$$

This difference in the resistance of full-sized locomotives is also used first of all

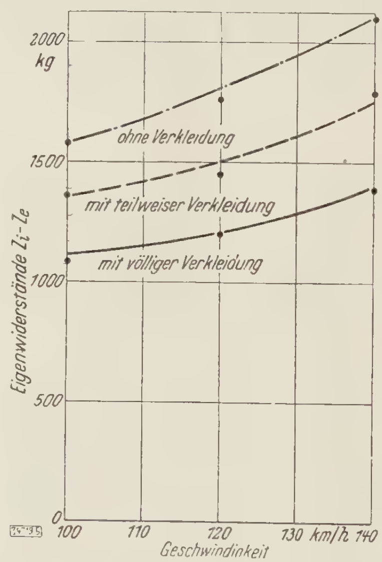


Fig. 5. — Resistances of the 03 locomotives when completely streamlined, partially streamlined, and non-streamlined.

Note. — Eigenwiderstände = resistances of the locomotives.

(11) According to VOGELPOHL, *Forsch. Ing. Wes.*, vol. 6 (1935), p. 217, it is probable that the exponent of the total air resistance (shape and area) is at times slightly lower than 2. But, at least for the locomotive and tender alone, the difference can be considered as practically insignificant.

(12) A. PARMANTIER finds (aforementioned article, p. 382) without explaining how he traced his curves from the different measured points, for the 4-4-2 streamlined locomotive of the P. L. M. Rys., the smaller value $k = 0.095$.

in the second part of the study, viz : in the comparison of the results — also determined as being tractive efforts — obtained in the Göttingen wind tunnel. As it is necessary for this comparison to be of a strictly aerodynamic character, it is of course incumbent on us in the first place to eliminate, in this case, the thermal gain in power due to the streamlining, which is only an *indirect* consequence. Now, this is what makes the above equation for the gain in tractive effort $Z+$, identical on principle with the diminution in the air resistance, because the Z_{iv}, which is slightly greater, is deducted from it, and with it the thermal gain that it includes. Another fact which permits one to say that we actually obtain only the gain in tractive effort solely due to the streamlining, is the elimination of all

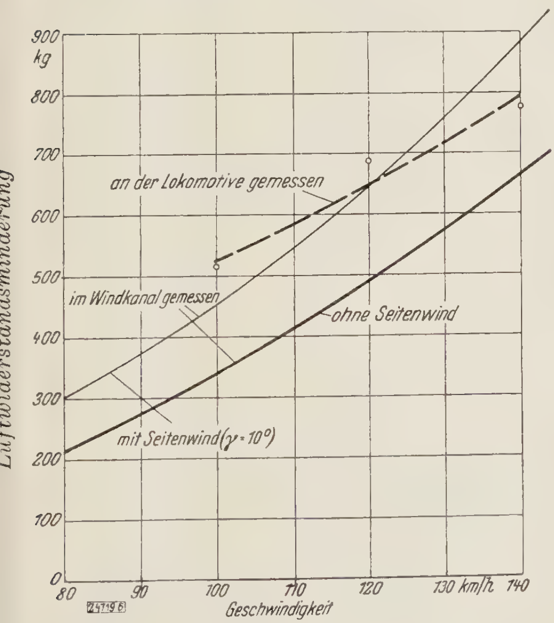


Fig. 6. — Reduction in air resistance due to complete streamlining, compared with wind tunnel tests.

Explanation of German terms:

An der Lokomotive gemessen = measured on the locomotive. — Im Windkanal gemessen = measured in the wind tunnel. — Mit (ohne) Seitenwind = with (without) side wind. — Luftwiderstandsverminderung = reduction in air resistance.

the variations in the tractive effort at the drawbar, in which the air resistance *does not intervene*.

These variations are due, first of all, to the influence of the differences in weight of the locomotive and tender. The tender of larger size, mentioned above, weighs 11.4 t. (11.2 Engl. tons) more; its influence on the tractive effort is translated with sufficient accuracy by 25 kgr. (55 lb.), by supposing a specific frictional resistance of approximately 2 kgr. (4.4 lb.) per ton. The 03.193 locomotive weighs 6.7 t. (6.6 tons) more, and its sister locomotive 03.154, originally semi-streamlined, weighs, after removal of the streamline side plates, approximately 1 ton more than the standard type of the 03 class. If, ignoring the friction resulting from the motion which may be taken as appreciably equal, we assume the specific friction to be approximately 2.5 kgr. (5.5 lb.) per ton, the difference in weight of 5.7 t. (5.6 tons) gives rise to a new corrective of 5.7 × 2.5 = 14 kgr. (30.9 lb.). Both should be added, because the corresponding gains in tractive effort due to the streamlining are absorbed by the increased weight of the streamline locomotive. Finally, it should be remembered that the runs under review of the non-streamlined locomotive took place in summer, and those of the streamlined locomotive in autumn, i. e., with a slightly denser air, barometer reading being appreciably the same, but with a lower temperature. The resistance of the non-streamlined locomotive must, therefore, be increased in order to bring it up to the value corresponding with this denser air. As the air resistance is :

$$W_l = q\, c_w\, F$$

($q = \rho \frac{V^2}{2}$ being the dynamic pressure of the air for the density ρ of the air and the speed V, c_w the coefficient of the equivalent area, and F the transverse area of the locomotive), c_w being

almost exactly equal to 1 (13) it is necessary to add a corrective $\Delta W_t = \Delta \rho c_w F \frac{V^2}{2}$, by deriving in each case $\Delta \rho$ from the data furnished by the reports of the trials on the average temperatures and barometer readings during the runs at 100, 120, and 140 km. per hour. The calculations show that these correctives amount to 18, 45, and 33 kgr. (40, 99, and 73 lb.).

the corrected value $Z_{eu} - Z_{ev}$ itself would no longer depend on the air resistance alone. Further on we shall see to what extent this assumption is justified; there is no inherent reason why it should not be so, and it is not possible to measure directly the air resistance by itself on the full-sized locomotive, as we have shewn. This corrected and real decrease in the air resistance is also represented graphically in figure 6.

By reason, therefore, of the law which

TABLE 2. — **Decrease in air resistance by complete streamlining.**

Locomotive.			100 km. (62 mil.).	120 km. (75 mil.).	140 km. (87 mil.).
03.154. not streamlined.	Actual resistance. $Z_i - Z_e$.	kgr. *(lb.).*	1520 *(3351)*	1812 *(3995)*	2103 *(4636)*
03.193. streamlined.		kgr. *(lb.).*	1120 *(2469)*	1203 *(2652)*	1398 *(3082)*
...	Gross decrease in air resistance.	kgr. *(lb.).*	460 *(1014)*	604 *(1332)*	705 *(1554)*
...	Increase for extra weight of tender.	kgr. *(lb.).*	+25 *(+55)*	+25 *(+55)*	+25 *(+55)*
...	Increase for extra weight of locomotive.	kgr. *(lb.).*	+14 *(+31)*	+14 *(+31)*	+14 *(+31)*
...	Increase for difference in temperature and in air pressure (*).	kgr. *(lb.).*	+18 *(+39.7)*	+45 *(+99)*	+33 *(+73)*
	Total decrease in air resistance.	kgr. *(lb.).*	517 *(1140)*	688 *(1539)*	777 *(1713)*

(*) During the trials of the streamlined locomotive 03.193 : air pressure, 742.4 to 767.5 mm. (29.2 to 30.2 in.) of mercury.

During the trials of the non-streamlined locomotive 03.154 : air pressure, 754.3 to 766.5 mm. (29.69 to 30.17 in.) of mercury.

Table 2 shews the gross values of the decrease in the air resistance, as well as the three corrective increases, and the total gains due to streamlining. It is drawn up with the assumption that the friction from the engine motion itself was equal in both cases, for otherwise

requires that the air resistance shall vary as the square of the speed, a law which also applies, of course, to the air resistance *differences,* these values must be placed on the parabola having as equation :

$$Z_+ = W_- = c \left(\frac{V}{10}\right)^2$$

However, if we form these « constants » by giving the values of c indices repre-

(13) H. NORDMANN, *Organ für die Fortschritte des Eisenbahnwesens,* vol. 72 (1935), p. 404.

senting the speeds and by writing down for example :

$$517 \text{ kgr.} = c_{100} \left(\frac{V}{10}\right)^2 = c_{100}\ 100,$$

the values of c_{100} and of c_{140} are not equal to 5.17 as for $V = 100$ km. (62 miles) per hour, but appreciably smaller, since $c_{120} = 4.77$, and notably $c_{140} = 3.96$ (14). The three small points reproduced in figure 6, when compared with the Göttingen test parabolic curve relative to the 1 : 20 model blown on axially, do not therefore furnish a parabola, but a flatter curve and moreover placed appreciably above the result obtained in the wind tunnel. Now, during the trials on the line, the wind always blew in variable directions, and with variable force; the speed of a slightly oblique head wind was, in a few cases, 6.1 m. (20 ft.) per sec. = 22 km. (13.7 miles) per hour; there was also a wind astern, reaching 3.75 m. (12.3 ft.) per sec. = 13.5 km. (8.4 miles) per hour. If, therefore, we again take up the above hypothesis, by approximating the resultant action of the wind to a contrary wind blowing at 10 km. (6.2 miles) per hour,

$$Z_{+} = c\left(\frac{V + 10}{10}\right)^2,$$

the differences per cent of the three values of c become smaller, it is true, but the absolute values, viz : $c_{100} = 4.27$, $c_{120} = 4.07$, and $c_{140} = 3.46$ still remain too divergent to determine, even approximately, a parabola. A further careful check of this rather unsatisfactory result has not, however, revealed any error.

The theoretical conditions would be satisfied if we could invoke reasons to justify the turn to the left of the curve in the field of the figure, i. e., a rise of the point corresponding to 140 km. per hour relatively to that which represents 100 km. per hour. In point of fact, the possibility of this turn is conceivable. As we have already mentioned by the way, we do not now employ, for the speed of 140 km. per hour, the test method in which a brake locomotive is used, because the two fastest brake locomotives are old express locomotives of the S. 10 class. On a favourable section of line, virtually on the level, the necessary adjustments for ensuring the same speed and the same indicated power, when a train is being hauled, are, it is true, still carried out satisfactorily, but all the same with less precision than is obtained with the brake-locomotive method; consequently, the position of the average values of the power for 140 km. per hour no longer offers the same guarantees of accuracy, and therefore *might* be able, by means of a reasoned-out correction, to furnish a better approximation towards the parabola. This doubtless would not be absolutely re-assuring, as a tolerance can also be negative.

It is for this reason that another circumstance is of greater importance, because it acts systematically in the desired direction. It relates to a fact to which Dr. VOGELPOHL, VDI., of the Aero-dynamic Institute of the Technical High School, Berlin, kindly drew our attention during a conversation about the unfortunate divergence from the parabola, viz : that, according to the English wind tunnel tests, the model of a streamline locomotive is influenced to a much smaller extent (at times even slightly negatively) by the angle of the resultant wind than the model of a standard locomotive (15). Under full-scale conditions with a constant natural wind, but with a decreasing train speed, the obliquity of the wind angle becomes greater (it is to be noted that at the proper time we examined various types of models with

(14) A. PARMANTIER found for his 4-4-2 locomotive a value of $c = 2.6$.

(15) F. C. JOHANSEN, *Proceedings of the Institution of Mechanical Engineers*, vol. 134 (1937), pp. 11-12; extract from this paper : G. VOGELPOHL, *Z. VDI.*, vol. 81 (1937), p. 1386, particularly figure 2, p. 1387.

a single air-stream angle = 10°). In other words, if it is desired to reduce the non-parabolic curve, obtained with weak winds, to complete calm, it is necessary for the drop to be relatively more accentuated at 100 km. (62 miles) per hour, for example, than at 140 km. (87 miles) per hour; for at the low speed, the air resistance would have been much increased under the action of a wind blowing at a greater angle. For this reason, we shall at the same time obtain a certain drop and *a certain rotation* of the curve. It remains to be seen to what extent a better approximation towards the parabola results from this.

Finally, we shall recall once more the hypothesis that the difference between the effective tractive efforts, at least after the correction for the difference in weights, *is caused only* by the variable air resistance. In order to establish whether this hypothesis is directly justified by the equality of the dimensions of the locomotives, and holds good as long as the test method employed is the same, we have reproduced in figure 7 the power curves for all the non-streamlined locomotives of the standard type tested up to date. Without going into the circumstances capable of causing small actual divergences — that would partly be a repetition — to which the tolerances provided for the calculations must be added either positively or negatively, from the moment the curves tally in a more or less satisfactory degree, it will be found above all that the measurements have effectively shewn up small divergences in the actual resistance. Moreover, these divergences not only manifest themselves by small parallel transpositions, but also by slight turns of the resistance curves in relation to each other. Here, once again, a reason can be found why the curve is not parabolic.

The best solution, therefore, undoubtedly appears to consist in repeating the tests later with two 03 locomotives, one of them streamlined and the other of the

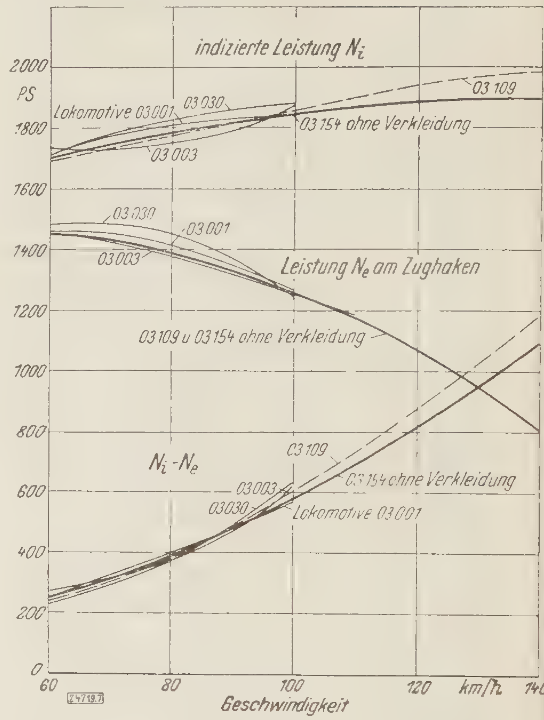


Fig. 7. — Powers of all the non-streamlined 03 locomotives examined up to date, the boiler working to the extreme limit of its capacity (57 kgr. of steam per m² [11.7 lb. of steam per sq. ft.] per hour).

Explanation of German terms:

Indizierte Leistung = indicated power. — Leistung am Zughaken = power at the drawbar. — Ohne Verkleidung = without streamlined casing.

usual type, by proceeding as we have recently done for the comparative resistance trials with express coaches of different types, viz : by running *two* test trains to the same timing, on the same day, the one a short time after the other. Under these conditions, the atmospheric pressure, the temperature of the air and of the wind, unless it is blowing a tempest, are practically the same, and a source of errors is avoided which can only be remedied by a correction made after the event by means of average values.

Comparisons of the trials on the line with trials made on models.

To sum up, the foregoing considerations shew in the last analysis the difficulties a trial on the line is up against. However, we should not be able to dispense with it, except in the case where, at the most, there is rather close agreement with the trial carried out on a model in the wind tunnel. Now, such is not the case here. In figure 6, the bottom curve is the result of the trials carried out in the Göttingen wind tunnel on the 1 : 20 model of the streamlined 4-6-4 locomotive with an 8-wheeled tender, the type of streamlining selected approximating to the original non-streamlined shape. It might be objected here in the first place, that the comparison with this locomotive of the later 05 class is not quite correct, in view of the fact that the latter is longer owing to the substitution of a bogie for the single trailing carrying axle, which results in an increase in the lateral air friction. For the locomotive of larger dimensions, there would result absolute resistances which would be slightly too high, too great a resistance difference, and finally, if it is desired to take the 03 class locomotive as a basis, slightly too high a position for the curves in the diagram. But, against this, the tender of the model is too small, for in the full-size the 05 locomotive, and particularly our 03 locomotive, were fitted with the large 10-wheeled tender, which, as compared with the 8-wheeled type, is slightly longer and therefore also has a greater lateral friction. Therefore, if the resistance opposed by the air to the model of the locomotive alone was a little too great in relation to the 03 locomotive, that of the model of the tender is too small. It is of course not possible to decide by speculative means whether these two differences completely and mutually compensate one another; a certain degree of compensation is incontestable, and on account of the compact shape of the 10-wheeled tender, it may be presumed that the model of the locomotive has the best of it to a certain extent, so that the curve in figure 6 is placed rather slightly on the high side.

Compared with the position of the wind tunnel curve for the purely axial air-stream, which curve is certainly not too low, that for the gain in tractive effort, passing through the three points for average moderate winds, and remaining below the annual average, is therefore placed rather higher. If this curve were, at least approximately, the parabola sought for, we could simply mark the upper position by means of the ratio to one another of the parameters of the two parabolas. In order, however, to shew at least the approximate value of this ratio, we may say that the point corresponding to 120 km. (75 miles) per hour in the diagram in figure 6 of the gain in tractive effort, is placed approximately 33 % higher than that of the trial on a model. In any case, it may be said that *the actual gain in tractive effort is appreciably higher, even with a slight wind, than that with the trial on a model in an axial wind stream.*

We have stated that at Göttingen, the air-streams were at an angle of 10°. But whilst all the various models, from the standard locomotive without any streamlining to the completely streamlined tank locomotive, running backwards, were blown on axially, we unfortunately confined ourselves at the time (in the 1933 spring) as regards the *oblique blowing,* to a certain number of types of models, sufficient to shew the considerable increase in the air resistance under the action of a side wind (16), but not sufficient to enable an immediate pronouncement to be made with regard to each model variety. This deficiency un-

(16) H. NORDMANN, *Organ für die Fortschritte des Eisenbahnwesens*, vol. 72 (1935), p. 401, figs. 7 and 8.

fortunately applies to the type of locomotive with tender chosen. It is true that there will not be a serious error if an average is struck between the two neighbouring models, as for continuous axial blowing. We then obtain the top parabola in figure 6 (with side wind), which, at 140 km. (87 miles) per hour, as is to be expected, is placed above the experimental values of the full-size locomotive. But at 100 km. (62 miles) per hour, the « full-size » trial point is found much above the trial point of the model. Perhaps there would again be a perfect agreement if, instead of $\gamma = 10°$, we had rationally employed, as is explained above, an increasing angle for the reduced speeds. As a matter of fact, $\gamma = 10°$ corresponds approximately, at 150 km. (93 miles) per hour, to the average speed of the wind over flat country, but is too small for a low running speed. It would therefore be necessary for the thin curve to be turned upwards at its left extremity, by pivoting round the point representing 150 km. (93 miles) per hour. It cannot obviously be stated beforehand by how much, and on the other hand when it is considered that at the three trial speeds the wind conditions do not agree, we must be content to state : *It is probable that the error in the catoptric method applied to the model is not very great as compared with the full-size with the relatively large scale of 1 : 20, but it will only be possible to find an exact mutual ratio by means of new trials.*

In view of this situation, it will of course be necessary to make a pronouncement according to the comparative trial of the full-sized locomotives; we have moreover taken the curve for the appreciably higher powers of the streamlined locomotive 03.193, as a basis for the indicator diagram, for establishing the timings.

[621. 335 (.44) & 621. 43 (.44]

High-speed diesel-electric locomotives of the French National Railways Company,

by Mr. TOURNEUR,

Engineer, Designs Office of the Western Region, French National Railways Company.

(Revue Générale des Chemins de fer).

The main line of the P. L. M. system, which extends for a little over 1 100 km. (684 miles) between Paris and Mentone, is travelled over by many « rapides », and express trains, the commercial speed of which, taken on the Paris-Nice run (1 088 km. = 676 miles), does not exceed 76 km. (47.2 miles) an hour except in one case, the « Côte d'Azur-Pullman », a relatively light « de luxe » train (averaging 328 tonnes), which accomplishes this journey in 12 hours 4 minutes, that is at an average of 90.2 km. (56 miles) an hour.

These speeds, which appear fairly moderate if compared with those obtained on other shorter lines, are actually restricted by various factors, which are as follow :

— The up and down gradient section of the Les Laumes-Dijon (57 km. = 35.4 miles) and Marseille-Fréjus (158 km. = 98.2 miles) lines, which have long gradients of 1 in 125;

— The location, which has led to the restriction of the maximum speed to 105, 95 and even 85 km. (65.3, 59.0 and 52.8 miles) an hour on various sections of the line, totalling approximately 180 km. (111.8 miles);

— Eight general stopping stations between Paris and Nice, and the necessity of slowing down when passing 19 special points, (stations, junctions);

— The heavy weight of the trains, which is frequently between 500 and 600 tons;

— Finally, because of the length of the run and the importance of the traffic, express trains follow each other every day at a few minutes interval on the 315 km. (195.7 miles) of the Paris-Dijon section, it has been necessary to draw up the timetables with sufficient margin to restrict the consequences of any unforeseen occurrence.

While pursuing a programme of improvement of the fixed installations and strengthening of the tracks, which will lessen the number of places where speed has to be reduced and increase the number of sections over which trains can travel at 130 and even 140 km. (80.8 and 87 miles) an hour, the former P. L. M. Company decided to experiment with new locomotives capable of performing long runs without taking on fresh supplies, developing all their power at the highest speeds, and having a sufficient excess power to assure good acceleration with heavy trains, a particularly useful characteristic on the main line, for the reasons given above.

Electrification of this long main line being out of the question at the present time, the P. L. M. Company decided to try diesel engines consuming a quantity of fuel small enough to allow the Paris-Mentone journey to be accomplished without refueling and which, through supercharging, develop under the required conditions of weight and size, the power necessary to haul heavy express trains.

As the result of competition opened in 1935, two experimental types of diesel locomotives were ordered respectively from the « Compagnie de Fives-Lille » and the « Compagnie des Forges et Aciéries de la Marine et d'Homécourt », the firms acting as general contractors.

Numbered 262-AD-1 and 262-BD-1, the locomotives were constructed to satisfy the following principal conditions :

— maximum axle load : 18 t. (17.7 Engl. tons);

— maximum weight per unit length over buffers : 7 t. per m. (2.1 Engl. tons per foot);

— to haul a train of 450 t. (443 Engl. tons) between Paris and Mentone or vice-versa without refueling, at a speed of at least 100 km. (62 miles) an hour with the track as laid;

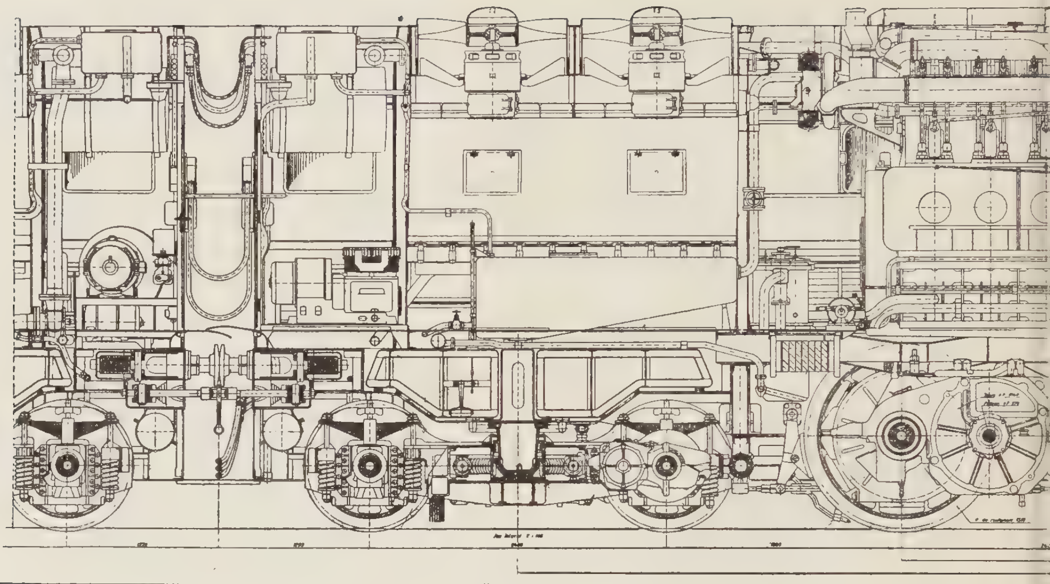
— to haul the usual 600 t. (590 Engl. tons) express trains in accordance with the timetables in force, which is at present done on the main line by 4-6-2 and 4-8-2 steam locomotives;

— to use ordinary grade fuel oil;

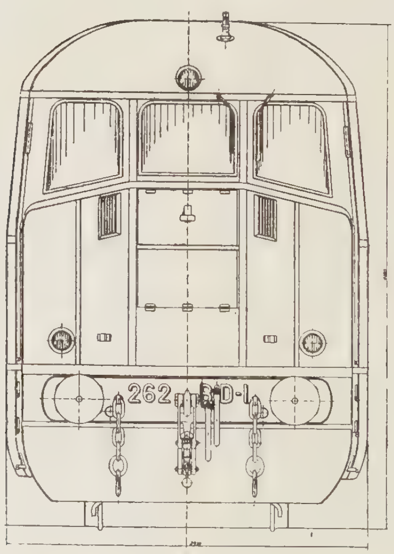
— to work at least 250 000 km. (155 350 miles) during each of the two years after being put into service, this guarantee of the builder being the subject of premiums or penalties fixed by the conditions of the contract.

The accomplishment of such a programme made it necessary to arrange for a continuous power of approximately 4 000 H. P. on the diesel shaft and, as with the relatively light 4-stroke engines which are used for traction purposes, the power per supercharged cylinder is still about 150 H. P., approximately 25 cylinders were deemed necessary. Actually the two locomotives carry 24 cylinders, distributed in banks of six on four crankshafts. The banking of the cylinders in this manner ensured the locomotive being well balanced, and it was possible to arrange two crankshafts, one beside the other, leaving sufficient space on each side of the engine groups, and still being within the international gauge.

Owing to the latter requirement, and the need for reducing the weight as much as possible, the adoption of an ar-

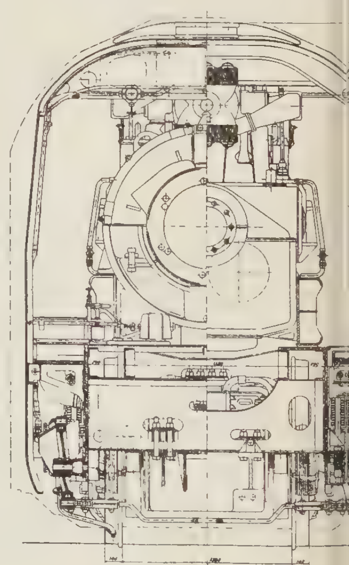


Front view.

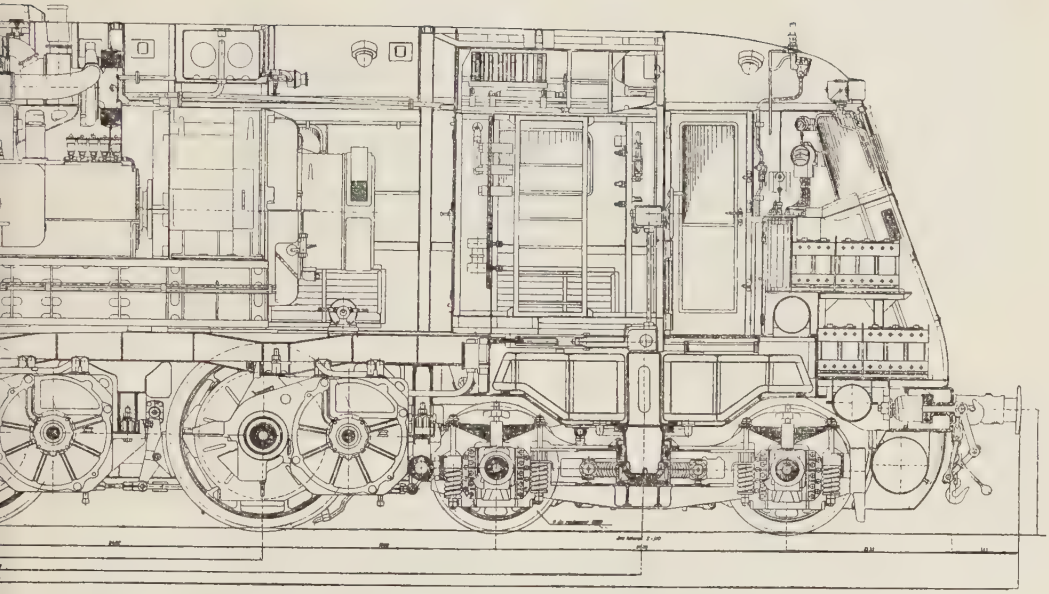


Half cross section in front of generator.

Half c section th motor-gen coupli



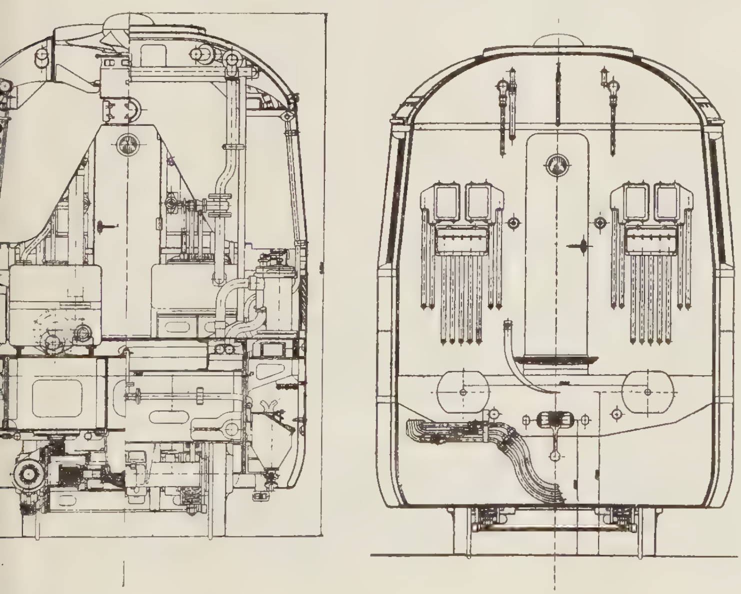
P. L. M. expre



lf cross n through equipment.

Half cross section facing the ventilation duct.

View showing the couplings of the two half locomotives.



e 262-BD-1.

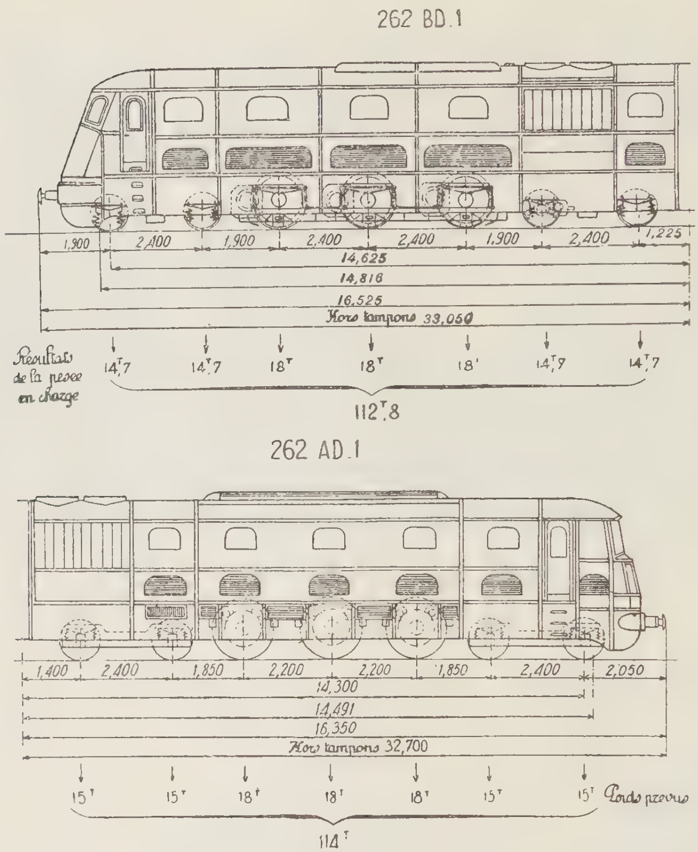


Fig. 1. — Diagrams of locomotives 262-BD-1 and 262-AD-1.

Note. — Hors tampons = over buffers. — Résultats de la pesée en charge = axle loads on rail in running order. — Poids prévus = estimated weights.

ticulated engine with a long body was impracticable. The locomotives are, therefore, made up of two identical units, always coupled together, each comprising an underframe with three driving axles between two bogies, being therefore of the $2'\text{-}C_0\text{-}2' + 2'\text{-}C_0\text{-}2'$ type.

The adhesive weight of 108 t. (106.3 Engl. tons) thus obtained may appear a little excessive for the service contemplated, but the restriction of the number of driving axles to four would not have markedly reduced the weight, and the wheel arrangement adopted will facilitate the starting of heavy trains. It should also be noted that electric transmission with automatic regulation of the power can bring about excessive high speeds of the traction motors in the case of skidding, and consequently a fairly large margin of safety has to be given.

Each of the two locomotives has the same general arrangement. In each unit the generator set is placed in a central compartment above the driving axles. The cooling equipment and various auxiliary groups border this compart-

ment on the side of the central coupling, and the electrical apparatus, on the other. This latter is thus adjacent to the driving compartment in front of which is a chest containing the battery of cadmium-nickel accumulators of the S. A. F. T. type.

The shape of the locomotives has been specially studied with a view to reducing air resistance. The framing is entirely encased and provided with inspection covers to facilitate maintenance. The sides and roofs of the two units are coupled together by a flexible bellows with a gangway to give connection between the two.

To facilitate the work of the staff and reduce the variety of spare parts required, it was stipulated that similar equipment should be used where possible.

For example, the two locomotives have the same brake equipment (automatic and moderable Westinghouse brake) (1), the same air compressors, (two compressors of the T. O. type per locomotive, made by Mssrs. « Manufacture Générale des Freins », each capable of delivering 2.640 l. [93.2 cu. ft.] per minute, measured at atmospheric pressure), the same general arrangement of the driving cabins, and numerous common details, such as axleboxes (2), draw and buffing gear of the standard type, Leach type air sanding gear, built-in electric lights, small electric auxiliaries, pressure gauges, thermometers, valves, signalling relays, P. L. M. type air whistle, etc.

Like all the P. L. M. locomotives, these have Flaman speed recorders with arrangement for registering signals at « stop ». Although two men are required for driving the locomotives, they are provided with Bianchi « dead-man » equipment, the assistant driver being frequently obliged to leave the driver's cabin to look after the diesel engines. In addition, audible warning devices enable the driver to call the assistant driver when the latter is not with him.

No train heating equipment has been installed in these trial locomotives, but a heating-boiler van will be attached in winter.

LOCOMOTIVE 262-BD-1.

Underframe, body, running gear, suspension.

The mechanical portion of the locomotive has been designed with a view to giving the generator sets as rigid a seating as possible, and to ensure very easy access to the various parts, especially the traction motors, the cylinders of the diesel engines and the auxiliary equipment.

The underframe of each unit consists of two steel solebars 25 mm. (1 in.) thick, cross-braced by the headstocks and bogie pivot transoms forming a box girder, and two groups of intermediate crossbars arranged one group above the driving axles and the other between these at about the height of the axleboxes. The traction motors, which are entirely suspended and have a single armature, are also positioned between the axles. They are connected to the frame by two fastenings (fig. 3) fixed under the adjoining crossbars and by a third fastening fixed to the crossbars situated above the axle. With this arrangement there is a good clearance above the motors and with the locomotive over a pit, the traction motors and upper inspection covers are very accessible.

Two pressed plate longitudes running along the solebars and connected to these and to the upper crossbars form a sub-frame to which the generator set is bolted.

(1) The braking coefficient is 85 % on the driving wheels and approximately 70 % on the bogie wheels. Arrangements have been made to allow for the substitution of double blocks for single blocks on the driving wheels if desirable.

(2) The bogies have ordinary inner axleboxes with lubricating pads, the driving axles being fitted with interchangeable outer axleboxes, with mechanical lubrication (Bourdon type on locomotive 262-AD-1, and Athermos type on locomotive 262-BD-1.)

Fig. 2. — Locomotive 262-BD-1 in the Paris station of the P. L. M.

All the cross beams are bent plates welded together but attached to the solebars by rivets.

The body framing is of rolled steel sections riveted together, and rests on cast steel brackets on the outside of the solebars. The side sheeting is of steel but the lower casing is of duralumin.

The roof, also of steel, has, above the Diesel engine, a clerestory of duralumin, which is very easily removed, thus allowing the cylinder heads and attachments to be quickly taken out. The roof, at the inner end, carries the two vertical motors of the coolers, which are placed along the side walls and made up, in each unit, of two groups of 18 elements, 10 of which cool the water while the remaining 8, placed in front of the former, cool the lubricating oil.

The floors are of duralumin chequered plate in the engine compartments and of wood in the driving cabins.

Many removable panels and inspection

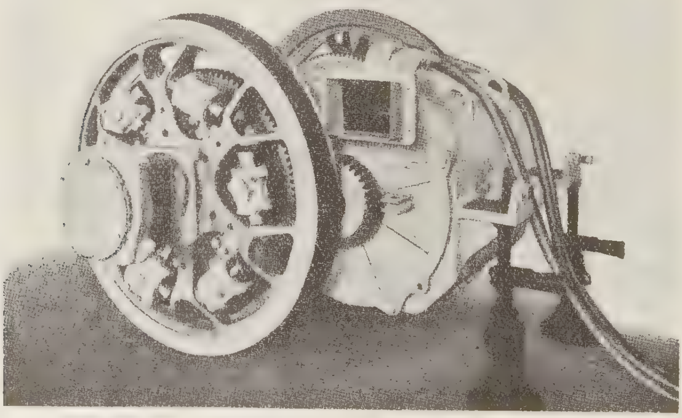


Fig. 3. — Locomotive 262-BD-1. — Traction motor mounted on wheels and axle.

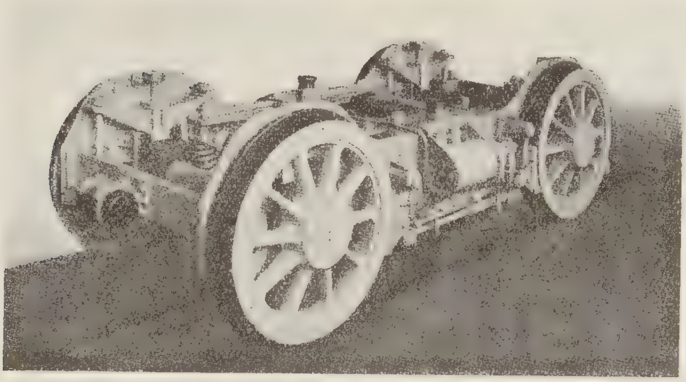


Fig. 4. — Locomotive 262 BD-1. — Bogie (exciter removed).

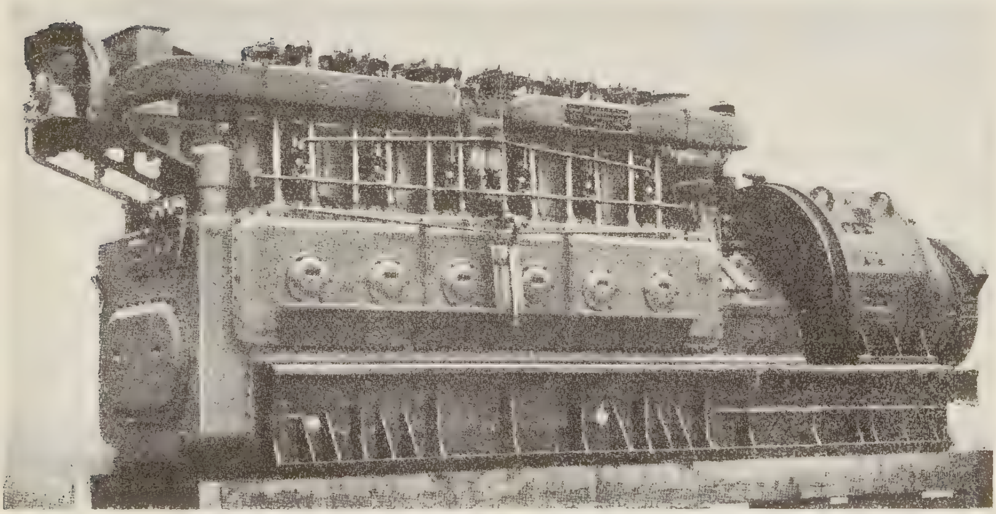


Fig. 5. — Locomotive 262-BD-1. — Generator set with 1 900-H.P. Sulzer diesel engine.

covers in the walls, the casing and the ends, give very easy access to the details (axle-boxes, cooling equipment, brake gear, accumulator batteries, feed pipes for the fuel, lubricating oil, water, etc.).

Four removable brackets are fixed to the solebars between the bogies and driving axles for taking the chains when lifting the locomotive in the Works. To avoid making the locomotive excessively heavy, provision for lifting the locomotive by the two headstocks in the case of a derailment has not been considered.

Each traction motor drives, by means of a solid double spur gear wheel having removable rims keyed to the wheels, a concentric hollow shaft on the axle run-

ning in bearings fitted with lubricator pads built into the motor casing.

The individual drive of the axles is of the well known A. E. G. Kleinow type which has already proved satisfactory on numerous electric locomotives, (*Reichsbahn* especially), and it has not been considered necessary to describe it.

The bogie frames are designed between the wheels and have spherical pivots (fig. 4). They are equipped with centring gear consisting of laminated and helical springs working in conjunction. Two side bolsters, each loaded to approximately 500 kgr. (1 100 lb.) damp out the bogie movements, the rotation of which is governed by a double spring stop which exerts a centring moment of approximately one tonne/metre (7 220 ft./lb.).

mechanical injection, type 12, LDA, 31, built by the « Compagnie de Construction Mécanique », St. Denis. This engine has 12 vertical cylinders 310 mm. × 390 mm. (24 3/16 in × 27 3/8 in.), arranged in two banks of six, which drive two crank shafts coupled with spur gears having a ratio of 42/35 to a single main generator which carries an auxiliary generator at the end of its shaft (figs. 5 and 6).

The diesel engine can work at four speeds 400, 500, 600 and 700 revolutions per minute, and can remain in service although the supercharging gear be out of order. The following table gives the powers developed on the shaft at the different speeds.

	Speed of diesel engine.	Speed of generator.	H. P. on shaft. without supercharging.	H. P. on shaft. with supercharging.
	R.p.m.	R.p.m.	H. P.	H. P.
Reduced working speed, N_1	400	480	750	685
Reduced working speed, N_2	500	600	1 290	850
Nominal continuous speed, N_2. . . .	600	720	1 900	1 030
Speed with supercharging, hourly rating, N_4	700	840	2 200	1 200

One of the axles of the inner bogies carries the exciter of the main generator, which will be described later. This machine, with a continuous rating of 6 kW., is nose-suspended.

The suspension springs of the driving axles are coupled by equalisers, thus making, with the bogies, a four-point suspension.

A short screw coupling and spring buffers couple the two units.

Diesel engines.

Each unit is equipped with a 4-stroke supercharged Sulzer-diesel engine, with

The engine base plate, which is also half of the gear box, is of cast steel in two parts welded together, and is firmly bolted to the two welded solebars which support the generator and constitute the auxiliary underframe of the generator set.

The steel crank shafts are forged in one piece, and run each in seven white-metalled steel bearings. The bearings on the gear side form stops and the crankshafts carry at the other end the control gear and a Sulzer-Sarazin shock absorber.

A careful choice of the order of ignition of the cylinders and the setting of the two crank shafts relatively to one another ensures satisfactory balancing of the motion

and allows of reducing the distance between the two crank shafts centres to 520 mm. ($20\frac{1}{2}$ in.), thus making it possible to arrange for two passages 400 mm. ($15\frac{3}{4}$ in.) wide on each side of the engine.

The cast steel cylinders are in two pieces welded together and enclose liners of special metal with copper joints in the upper, and rubber in the lower portion.

Each cylinder has an independent cast iron head with an inlet and an outlet valve. The rods attached to light-alloy pistons are fitted with bronze-lined bushes which can easily be replaced from the top. Two camshafts directly drive the individual injector pumps of the Sulzer type (injection pressure: 275 kgr./cm² = 3 910 lb. per sq in.) and, through rockers, also control the valves.

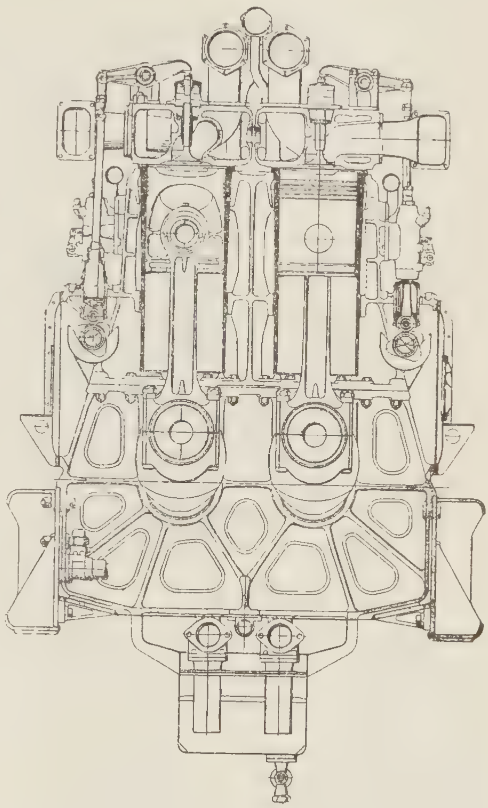


Fig. 6. — Locomotive 262-BD-1. — Cross section of a diesel engine.

The supercharging is carried out by two Rateau exhaust gas turbo-blowers fitted at each end of the engine, supplying respectively the two groups of three cylinders nearest to them (fig. 7). The turbine has one wheel and two groups of nozzles fed respectively by each group of three cylinders, and each of these is supercharged by means of a collector arranged on a half-circumference of the blower wheel.

At the nominal continuous rating of the engine (1 900 H. P. — 600 r.p.m.) their working characteristics are as follows :

Speed	10 250 r.p.m.
Temperature of exhaust gas	
at inlet.	520° C. (1 068° F.).
at outlet	495° C. (923° F.).
Average gas pressure at inlet. .	0.225 kgr./cm² (3.2 lb./sq. in.).
Supercharging pressure	0.300 kgr./cm² (4.27 lb./sq. in.).

The exhaust gases are discharged directly to the atmosphere through the centre of the roof.

The servo-motor governor which works on the injection control shaft regulates the working speed at the four ratings shown above with a decrease of approximately 7 % at 600 r. p. m. The changes of rating are obtained by modifying the tension of the springs by means of a pneumatic arrangement worked by three electro-valves. Other electro-valves control: (1) the stopping cylinder, (2) the cylinder reducing the injection when starting, and (3) the device limiting the injection of fuel at the various ratings.

The cooling water of each engine is drawn from two tanks, placed under the cooling equipment, by a horizontal set made up of a 5.5-H. P. motor driving a centrifugal pump, which forces it into the engine where it passes through the

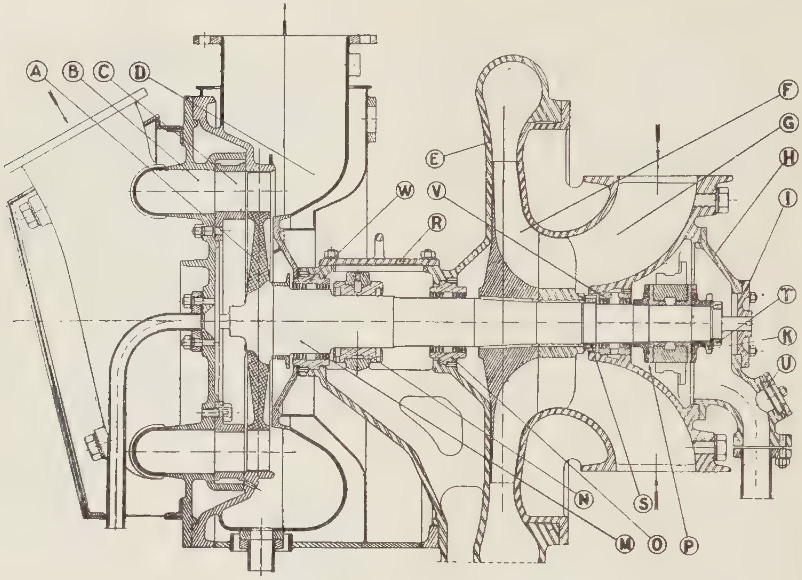


Fig. 7. — Locomotive 262-BD-1. — Cross section of a rateau turbo-blower.

cylinders and then through the heads. The fuel-oil is heated by by-pass pipes when passing through the filters. The water returns to the tanks after passing through the cooling equipment above which an equalising reservoir is provided. The cooling is regulated by altering the speed of the ventilators, the motors of which can be coupled in series or in parallel, or by working on the by-pass valves arranged between the inlet and outlet of the cooling equipment. A blower located in the tanks can be fed with steam at the depot in order to preheat the engine before starting.

The fuel in each unit is carried in four reservoirs, which have a total capacity of 3 700 l. (814 Br. gall.), and are fitted above the bogies, between the solebars. Two groups of electric motor pumps, one spare, deliver into an auxiliary reservoir of 325 l. (71 1/2 Br. gall.) whence it flows to the injection pumps of each line of cylinders passing through a meter and a filter.

Each crank shaft drives an oil pump delivering approximately 5 l. (11 Br. gall. per sec.) at 700 r.p.m. One of these pumps, called the circulating pump, draws the warm lubricating oil from the first compartment of the crank case and forces it into the oil coolers, whence it passes into a second compartment of the crank case. The oil thus cooled is taken up by the second pump, called the lubricating pump, which sends it, after passing through a filter, to the various parts requiring lubrication (shafts, rod ends, camshaft, turbo-blowers, gears), to the governer, and to the safety servomotor, which will be referred to later.

At the time of the trials in the Works, the consumption of fuel and lubricating oil reached respectively 167.9 and 155 gr. (0.375 and 0.357 lb.) per H. P.-hour at the nominal power.

Electrical equipment.

The two electric transmissions which automatically regulate the power supplied by the diesel engines were built by the « Forges et Ateliers de Constructions Electriques de Jeumont », and are

of their design with axle-driven exciters, as have already been used on less powerful equipment (1). They each consist of :

— A ten-pole compensated main generator, the armature of which is mounted on a cast steel hollow shaft by a rigid coupling plate (fitted bolts) to the shaft of the control gear, which is carried in two bearings on either side of the spur wheel. At the other end, the armature shaft is screwed on to a forged steel shaft, which rotates in the single bearing of the main generator, and carries the armature of the auxiliary generator on the overhanging portion.

— Three exciting windings are mounted on the main generator : — one series winding which is not used in traction but starts the diesel engine, the generator working as a series motor fed by the battery, and two other separate exciting windings, the function of which will be described later.

— Three traction motors with series winding, which are fed by the main generator and constantly coupled in parallel. The inductors are automatically shunted when the locomotive is travelling at high speeds.

— One double-wound exciter driven by a bogie axle, which feeds one of the separate exciting windings of the main generator.

The main generator is self-ventilated, the used air taken from the engine compartment being discharged directly to the atmosphere, while the ventilation of the traction motors is carried out by a 19-H.P. motor ventilator set.

The powers, characteristics and efficiency of these machines, noted during the trials on the test bench, are as shown in the table hereafter.

—	Main generators.	Traction motors.
Continuous rating :		
Speed (r.p.m.)	750	1 140 (110 km./h.= 68.3 m.p.h.)
Power	1 220 kW. at terminals.	500 H.P. on the shaft
Terminal voltage (V)	790	790
Intensity (A)	1 545	515
Maximum heating (2)	103° C. (217° F.)	120° C. (248° F.)
Efficiency (%)	93.3 (3)	92.4 (without gears)
Hourly rating :		
Speed (r.p.m.)	835	880
Power		(85 km./h. = 52.8 m.p.h.)
Terminal voltage (V)	1 420 kW. at terminals.	580 H.P. on the shaft.
Intensity (A)	1 800	600
Maximum heating (2)	116° C. (240° F.)	120° C. (248° F.)
Efficiency (%)	92.9 (3)	92.1 (without gears)

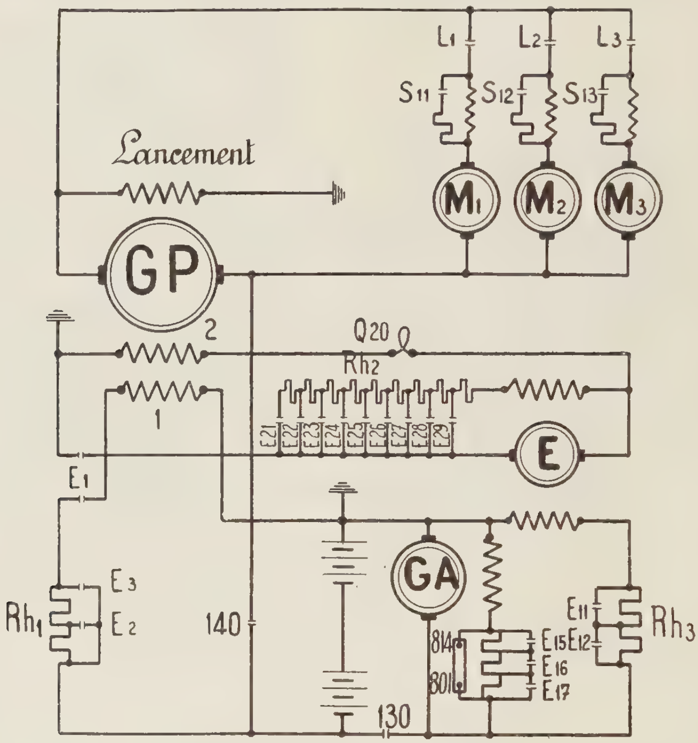
(1) In particular the 900-H.P. diesel-electric locomotives of the Congo-Océan Ry., and the express railcar sets of the former Nord Railway.

(2) The C. M. T.-18 regulations permit 120° C. (248° F.) for armatures and inductors at the continuous rating (by resistance variation).

(3) Excluding losses due to bearings, but including losses through auxiliary generator ventilation.

Fig. 8. — Locomotive 262-BD-1. — Wiring diagram of the equipment.

Note. — GP, main generator. — GA, auxiliary generator. — E, exciter on axle. M1, M2, M3, traction motors.



Tables showing the interlocking of the contactors.

Diesel speed	Control panel	Cam shaft	Individual contactors.													
			140	E1	E11 E15	E12 E16	E17	E21	E22	E23	E24	E25	E26	E27	E28	E29
Start	0	0														
	0	0	×													
400 r.p.m.	A	1		×	×	×	×									
	B	2		×	×	×	×									
	C	3		×	×	×	×									
	1	3 or 7 dependent on Q 20		×	×	×	×		×							
500 r.p.m.	2			×		×	×								×	
	3			×		×	×						×			
	4			×		×	×					×				
	5			×		×	×	●						⊕		
600 r.p.m.	6			×			×					●				⊕
	7			×			×				●				⊕	
	8			×			×			●				⊕		
	9			×			×		●				⊕			
	10			×			×	●				⊕				
700 r.p.m.	11			×						●						
	12			×								●		⊕		

Cam shaft.									
Steps	801-814	L1	L2	L3	E2	E3	S11	S12	S13
0	●								
1		●	●	●					
2		●	●	●	●				
3		●	●	●	●	●			
4		●	●	●	●	●			
5		●	●	●	●	●	●		
6		●	●	●	●	●	●	●	
7		●	●	●	●	●	●	●	●

In the left-hand table.

× Contactors dependent exclusively on the control panel.

● Full field } Dependent on the cam shaft.
⊗ Shunt }

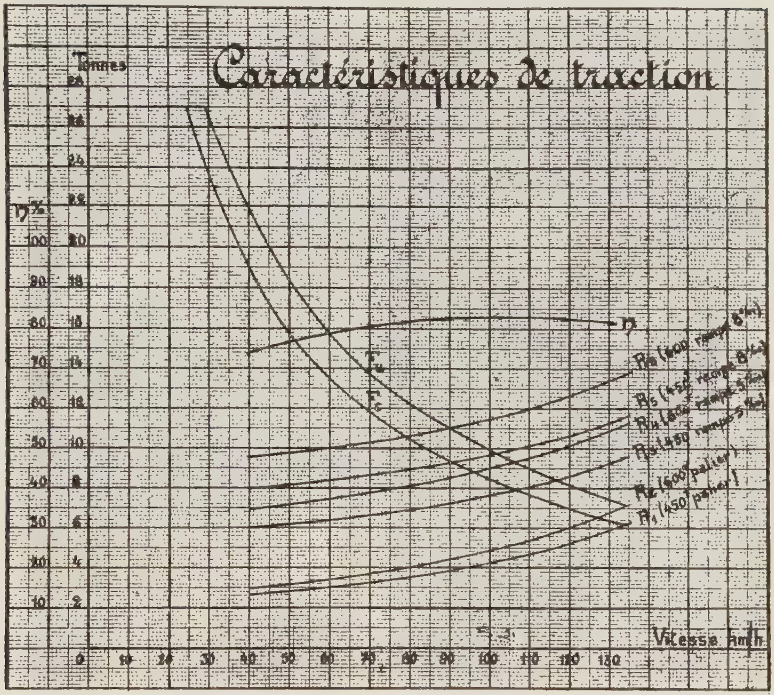


Fig. 9. — Locomotive 262-BD-1. — Calculated characteristics.

N. — Total efficiency of the locomotive, from the diesel shaft to the tread of the driving wheels (deduced from the trials on the test plant).
F_c, F_u.— Tractive efforts at the tread corresponding to the continuous and hourly-rating power of the diesel engines.
R_1 to R_6. — Resistance to running of the locomotive and train.

Should a generator set happen to fail, the driver would be able either to put the corresponding unit out of action, thereby halving the tractive effort at the tread, or to cut in, by means of reversers, the group of traction motors corresponding to the defective generator set in the traction circuit of the other unit, in series with the three other motors, thereby maintaining the same tractive effort at the tread but reducing the speed of the locomotive by half.

We will confine ourselves to going over the principal features of the *Jeumont electric drive.*

The regulation of the running of the locomotive is carried out solely by means of the acceleration handle of the controller, which has in addition to the zero step, three others, A, B and C for starting and 12 for increasing the power, ranging from 925 to 3.550 H.P. The working speeds of the diesel engines at the various steps are as follows :—

Steps	A, B, C, 1 :	400 r.p.m
»	2 to 5 :	500 »
»	6 to 10 :	600 »
»	11 and 12 :	700 »

With the starting steps A, B and C, the main generator is excited only by winding 1 (fig. 8), connected to the accumulator battery by an adjustable rheostat Rh_1.

With the 12 running steps, winding 2 is fed by an exciter which has a separate excitation winding and a shunt winding. The power

variations for the same speed of the diesels are obtained through the shunt winding (rheostat Rh_2). When the working speed of the diesels is reduced, the separate exciting winding of the exciter is altered to suit (rheostat Rh_2). When the acceleration handle is maintained on one of the 12 automatic running steps, the power output of the diesel engines remains practically constant (fig. 9). If, for example, the speed of the locomotive diminishes because of an increase of the tractive effort at the thread, the current from the generators increases but the voltage drops because of the decrease in the electromotive force of the exciter.

It should be noted that in the case of failure of one of the cylinders of an engine, this transmission might overload those cylinders remaining in service. Similarly owing to the importance of the induction windings of the main generator, the variations in temperature of these have a considerable influence on the regulation of the power, and the diesels might be overloaded when starting up the locomotive with the engines cold. Such overloads could have been prevented by limiting, by means of stops on the pump governors, the quantity of fuel which could be injected into the cylinders;

In the above cases, and taking into account the transmission characteristics, the speed of the diesel engines might have been lowered by approximately 15 %. Although such speed reduction is not troublesome, as no appreciably critical speed occurred below 700 r.p.m. at the reception trials, the problem has been solved by having small rheostats inserted in the separate winding of the exciter, worked through the gear controlling the fuel pumps, which rheostats reduce the excitation if there is a tendency to overloading. These details are also under the control of manostats inserted on the supercharging air conduits and they automatically reduce the power required from the diesel engines when a turbo-blower is out of order.

A battery of accumulators composed of 90 S.A.F.T. cadmium-nickel cells, having a capacity of 398 amp.-h. and a normal discharging period of 5 hours, is used for starting the generator sets. The cells are distributed half on each unit and are normally charged by the two auxiliary generators coupled in parallel, which feed the battery by means of reverse current cut-outs and charging resistances. The battery also feeds at 120/150 volts the operating and control circuits, as well as the air compressors and water circulation pumps. The ventilators, fuel feed pumps and driving compartment electric heaters are connected to the auxiliary generators.

A cam-shaft commutator governed by a JH electric servo-motor controls the traction circuits (reversers, motor contactors, shunting of windings). The individual contactors of the auxiliaries and the regulation of the exciters are of the electromagnetic type.

Driving compartment (fig. 10).

In addition to the usual valves for operating the automatic and moderable brake, the driver has a 4-lever control panel, viz :

— two levers for starting and stopping the generator sets, which are brought back to their zero position by springs;

— an acceleration lever with 16 positions, which regulates the power developed. The operation of this lever has been explained proviously;

— a removable reversing lever which, when withdrawn, locks the acceleration lever at zero and isolates the circuits controlled by the starting levers and all the control push-buttons of the auxiliaries arranged on the panel.

The measuring apparatus, placed so that they can be seen by the driver, have been reduced to the absolute minimum, i. e.

Two tachometers (one for each diesel engine), two ammeters giving the output of each main generator, locomotive speed indicator, and triplex brake pressure gauge. A small panel on the back wall of the compartment carries the battery voltmeter and ammeter, and the auxiliary generator ammeter.

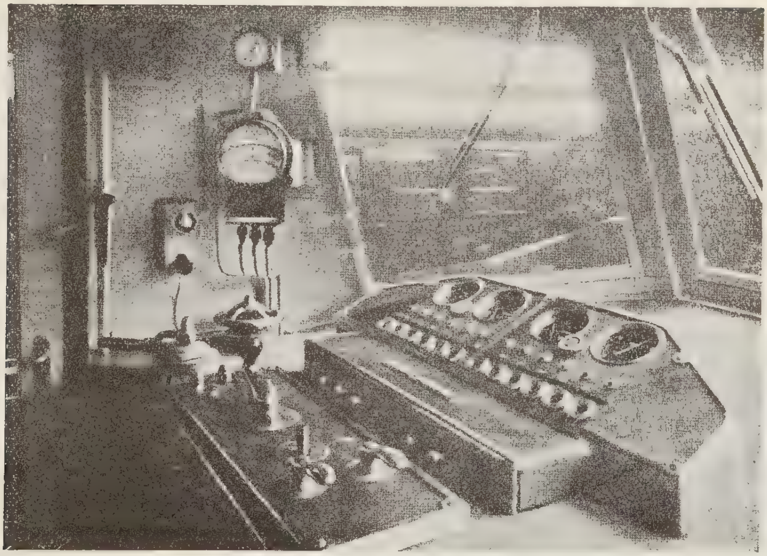


Fig. 10. — Locomotive 262-BD-1. — Driver's compartment.

Should a diesel be accidentally overloaded, the temperature of the water or oil be excessive or the pressure of water or oil be abnormally low, the driver's attention would be called thereto by pilot lamps on a panel. The lighting up of a lamp is accompanied by the sounding of a klaxon, which the driver can stop by pressing a button. The lamp, however, does not go out until the irregularity ceases. Another push-button enables the driver to control at any time the correct working of these signalling details.

Should the pressure of water or lubricating oil fail, the corresponding diesel engine is automatically stopped.

The following table gives particulars of the weight of the locomotive and its various parts :

— Frame, body, wheels and axles, suspension.		94 750 kgr.	*(208 890 lb.)*
— Brakes (rigging, compressors, reservoirs and compressed air details)		8 100 kgr.	*(17 860 lb.)*
— Generator sets :			
diesel engines.	41 200 kgr. (90 830 lb.)	61 200 kgr.	*(134 920 lb.)*
generators . .	16 000 kgr. (35 270 lb.)		
framing. . .	4 000 kgr. (8 820 lb.)		
— Diesel auxiliaries (cooling equipment, pumps, ventilators, reservoirs)		13 505 kgr.	*(29 770 lb.)*
— Battery of accumulators		3 170 kgr.	*(6 990 lb.)*
— Traction motors (without gears)		24 660 kgr.	*(54 360 lb.)*
— Electric apparatus and wiring.		6 870 kgr.	*(15 150 lb.)*
— Complement of	fuel oil.	7 000 kgr.	*(15 430 lb.)*
	lubricating oil	1 440 kgr.	*(3 170 lb.)*
	water	3 280 kgr.	*(7 230 lb.)*
	sand.	400 kgr.	*(880 lb.)*
— Miscellaneous		1 225 kgr.	*(2 700 lb.)*
	Total . . .	225 600 kgr.	*(497 350 lb.)*

LOCOMOTIVE 262-AD-1.
Underframe, body, running gear, suspension.

The traction motors which are entirely suspended and have two armatures, are positioned above each driving axle and are similar to those on electric locomotives. The underframe has the usual features, the steel solebars being 26 mm. (1 1/32 in.) thick, cross-braced by riveted box beams made of plates and angles, and forming the bogie pivot transoms and engine supports. The latter are secured to the underframe at four points by bolts and cotters and assist in making the underframe rigid. A continuous flooring of metal plates, 5 mm. (3/16 in.) thick, is provided between the solebars throughout the length of the underframe, and together with the transoms of the traction motors form a seating for the main generator sets.

The two headstocks, reinforced by steel castings, are respectively equipped with the standard buffing and drawgear, and the special coupling gear between the two units of the locomotive. This coupling gear (fig. 11) consists of a flexible drawbar and a central buffer

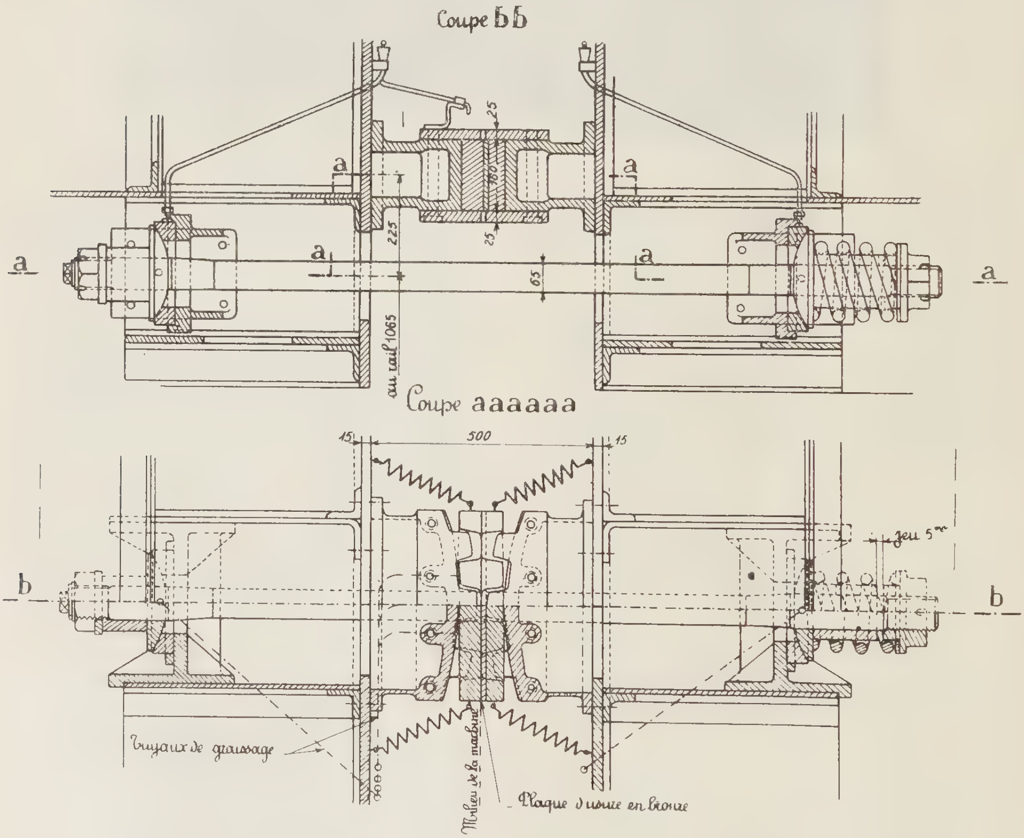


Fig. 11.

Note. — Coupe = section. — Au rail = above rail level. — Tuyaux de graissage = lubricating pipes. — Milieu de la machine = middle of the locomotive. — Jeu = play. — Plaque d'usure en bronze = bronze wearing plate.

which allows for all the relative transverse displacements of the two units.

The body framing and the side panels, which are easily taken down, are of steel. A large portion of the lower sheeting and the whole of the roof are of aluminium. Two men can take out in a few minutes the central clerestory which gives access to the cylinder heads of the main diesel engines.

Covers in the floor permit easy access to the brushes of the traction motors during running. It is also possible to obtain access to these through flap doors under the engines when the locomotive is on a pit. The lifting of a unit is carried out either by means of jacks placed under the solebars between the bogies and the adjacent driving axle or by scotching the locomotive at one of these points and lifting at the opposite headstock.

Each double traction motor (fig. 12) drives a hollow shaft by a single solid spur gear wheel (in one piece shrunk hot onto the hollow shaft) which is coupled to the axle by means of a group of elastic couplings of the Sécheron-Meyfarth type.

These latter (fig. 13), consist of springs which are mounted half-way between the cylindrical outside cases and sliding pistons which act on the spokes of the wheels through spherical headed rods.

This arrangement gives 4° of movement for a load on the tread = 25 % of the adhesive weight.

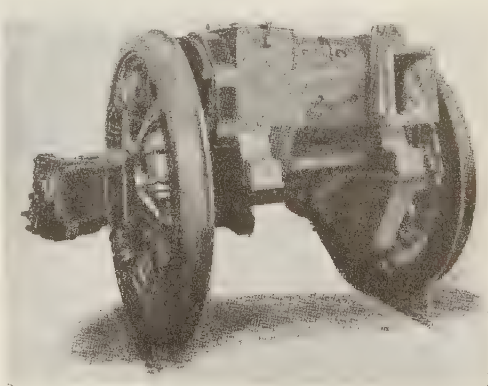


Fig. 12.

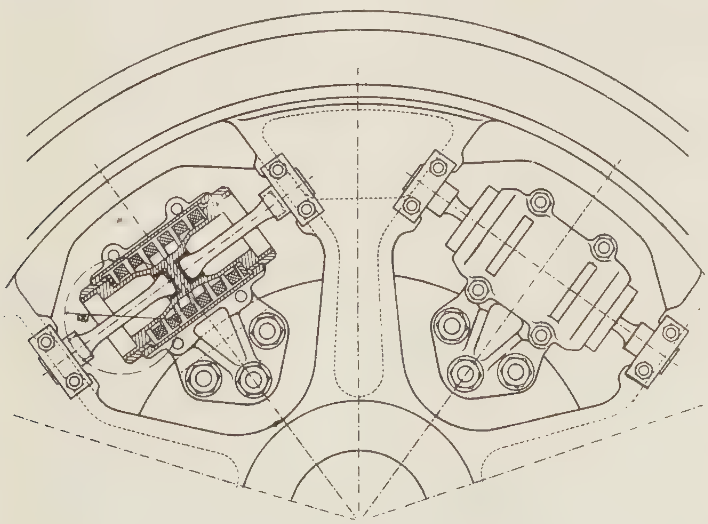


Fig. 13.

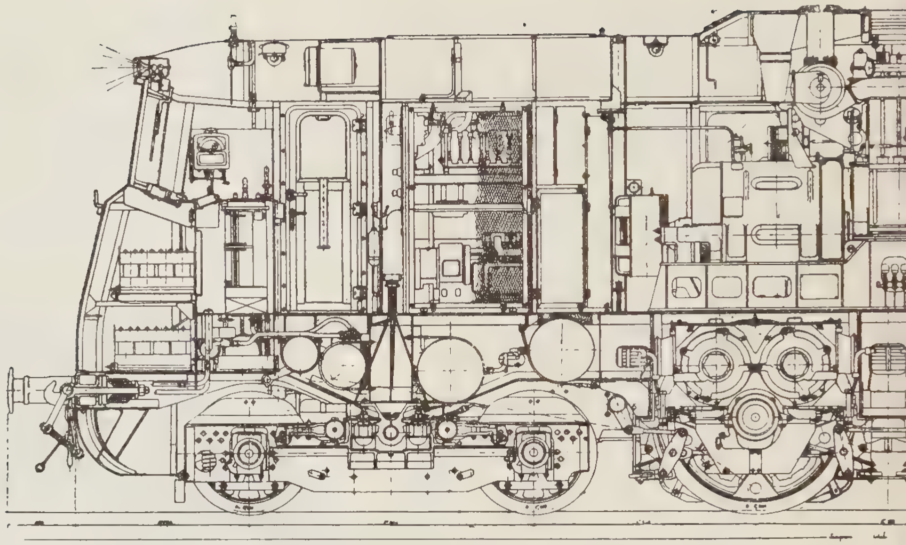


Fig. 14. — Type 4-6-4 + 4-6-4 high-speed diesel-electric locom

The bogies are of the type used on most express electric locomotives of the French National Railways with the Winterthur centring equipment [1].

The suspension of the locomotive is similar to that of locomotive 262-BD-1, i.e. 4-point suspension by connection of the springs of the driving wheels by equalisers.

Main and auxiliary generator sets.

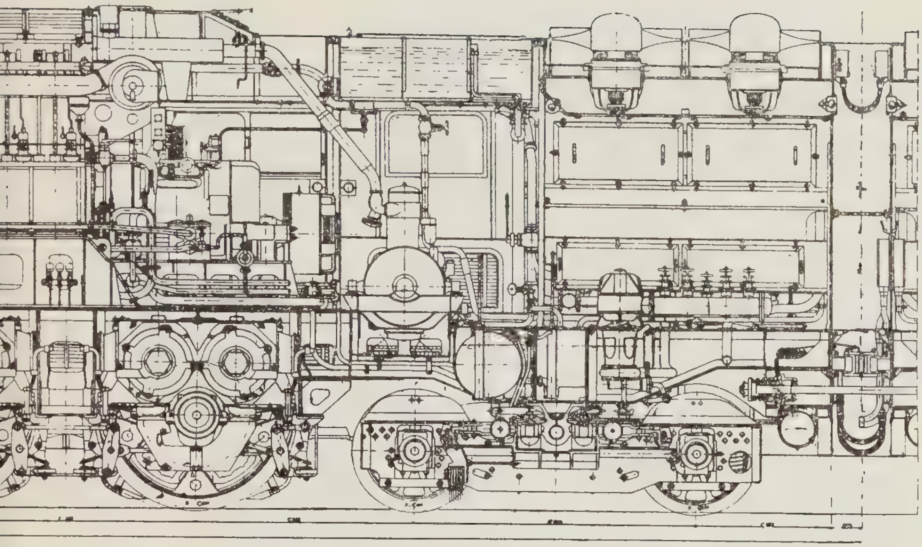
Whilst locomotive 262-BD-1 is equipped with two generator sets of 1 900 H. P., locomotive 262-AD-1 has six generator sets, four main sets of 950 H. P. and two auxiliary of 130 H. P.

This was done as it was thought advisable to use only arrangements which had been previously proved on other locomotives (sets of equal and fairly low unit power as already in use, direct driving of the generators, without gear wheels), so as to affect the performance of the locomotive as little as possible should a diesel engine fail. It was also considered that it would be interesting, by making comparisons of the two arrangements, to ascertain the advantage of the use of two autonomous sets for feeding the auxiliary duties. This arrangement, of course, makes the electric and auxiliary equipment more complicated and it should be noted that the comparatively low power of the main diesel engines used, but which together are slightly more powerful than those of locomotive 262-BD-1, greatly facilitated putting it into practice.

On each unit the two main generator sets are arranged one beside the other (fig. 15) on a common auxiliary frame which is bolted onto the locomotive underframe, above the three driving axles. The orientation of each set is different, so that the generators are opposite one another and the details requiring maintenance (injection pumps, valve gear) face the side corridors 50 cm. (19 3/4 in.) wide, facing the engines.

The main supercharged diesel engines

(1) Cf. *Revue Générale*, July 1927.



udinal section (one half locomotive, driver's compartment « A » side).

with direct mechanical injection are of the M. A. N. high-speed type with six 300 mm. × 380 mm. (11 13/16 in. × 14 15/16 in.) cylinders and were constructed by the Société Générale de Constructions mécaniques (S. G. C. M.), La Courneuve. They have many features similar to those of the locomotives of the Congo-Océan Railway. The table below gives the H. P. developed at different speeds :

frame and carries the crank shaft bearings. 7 pairs of stay bars tie it from top to bottom and prevent any tendency of the framing to distort, due to their initial tension.

The subframe, which is similar for both engines, is built up of welded plate (fig. 16) and braces each pair of supports of the engine framing. It also forms the lower crank case.

The brasses of the crank shaft bearings are of white-metalled bronze and those of the

	Speed (r.p.m.).	H.P. on shaft.	
		With supercharging.	Without supercharging.
Reduced speed, N_1	500	500	450
Nominal continuous speed, N_2	700	950	630
Hourly supercharged speed, N_3	700	1 050	690

The framing of each engine, which is fitted with removable cylinder liners, is of special cast iron and in one piece. The lower part provides the supports resting on the sub-

connecting rod ends of special lead bronze. The light-alloy pistons have 8 rings, 3 of which are scrapers.

The heads, which are made of special cast

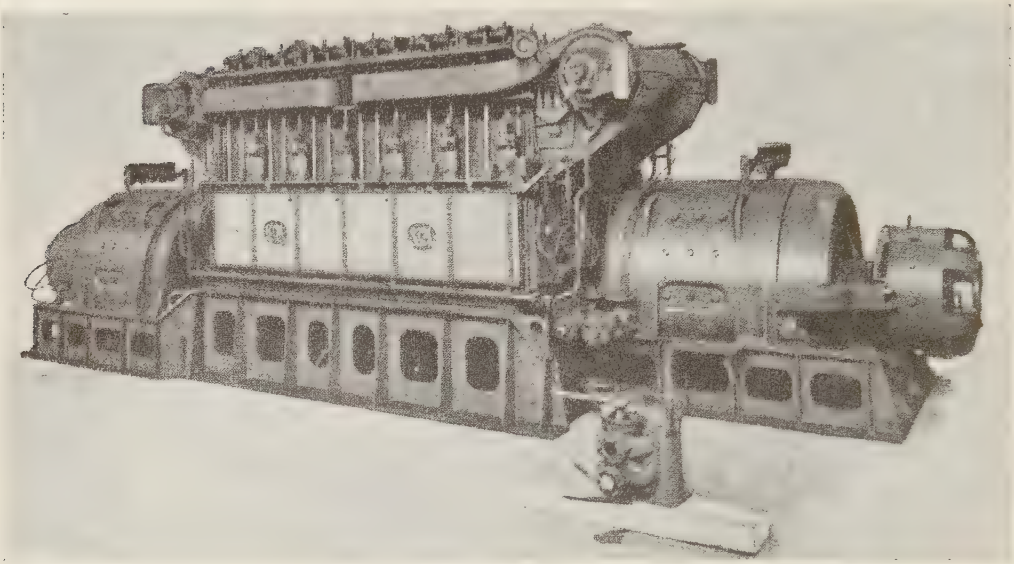


Fig. 15.

iron (one per cylinder), are attached to the framing by gudgeon pins adjacent to the stays, and carry two inlet and two outlet valves governed by rockers and levers on which works a cam shaft placed midway up the framing, and which also carry the adjustable cams governing the individual injection pumps built by the S.G.C.M. The necessary quantity of fuel is obtained by the action of a discharge valve controlled by the speed governor. The water cooled injectors are of the M.A.N. type.

The speed governor is controlled by electro-valves, as on locomotive 262-BD-1.

At both ends of each engine, a Rateau supercharging turbo-blower is fitted horizontally and connected to the three adjoining cylinders (that is 8 turbo-blowers for the locomotive). These have features very similar to those on locomotive 262-BD-1. Their speed reaches 16 000 r.p.m. at the nominal power of the diesel and they weigh approximately 130 kgr. (287 lb.).

Each main diesel engine has two lubricating pumps (fig. 18). One circulates the oil to the details to be lubricated (shaft, connecting rod ends), the other, of a slightly higher capacity, pumps oil from the engine casing and forces it first into the cooling equipment and then into a 450 l. (99 Br. gall.) reservoir formed by the bogie bolster, which is common to both engines of the unit.

The fuel-oil for the main diesel engines of each unit is stored in two reservoirs each having a capacity of 1 700 l. (374 Br. gall.), both of which feed the engines. They are above the auxiliary set and the accessories compartment and have rapid discharge equipment by remote control from the driving compartments. On each engine a feed pump equipped with a discharge valve permanently maintains pressure in the pipes leading to the injection pumps.

During the bench tests the average consumption of fuel by the main diesel engines was as under :

167.9 gr. *(0.370 lb.)* per H.P.-hour under 1/2 load;

164.7 gr. *(0.363 lb.)* per H.P.-hour under 3/4 load;

171.5 gr. *(0.378 lb.)* per H.P.-hour under full load (950 H.H., 700 r.p.m.).

The consumption of oil under full load was 5 gr. (0.176 oz.) per H.P.-hour.

The auxiliary generator set mounted on each unit (fig. 17) consists of a Saurer diesel type BXD engine with 6 134 mm. × 180 mm. (5 9/32 in. × 7 5/64 in.) cylinders in line, driving a generator able to develop a continuous power of 105 kW. at 1 500 r.p.m.

This type of diesel engine is in service on a large number of railcars, where it is used at a nominal power of 160 H.P. at 1 500 r.p.m. On the locomotive, the necessary power required in normal service for feeding the auxiliaries is not more than 100 H.P., so that it was possible to restrict the maximum

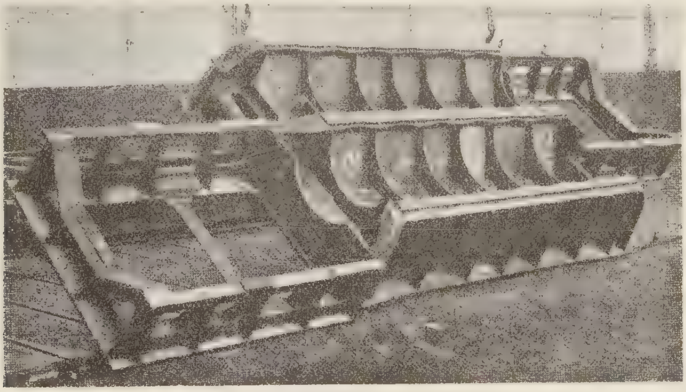


Fig. 16.

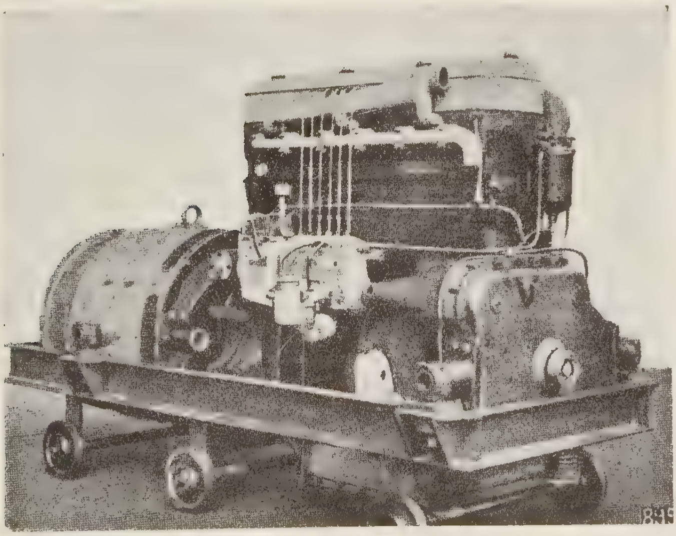


Fig. 17.

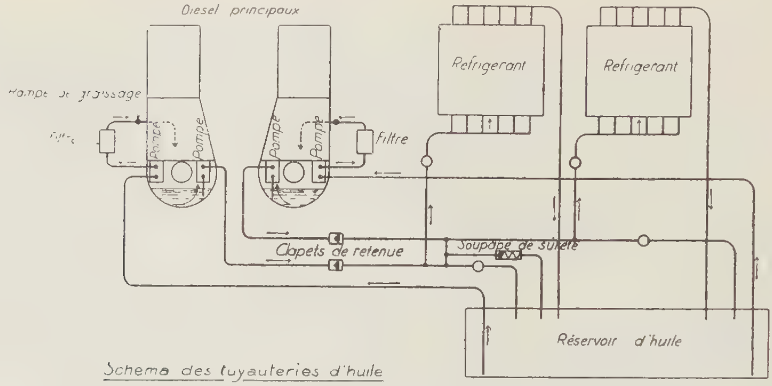


Fig. 18. — Diagram showing lubrication piping.

Explanation of French terms :

Clapets de retenue = retaining valves. — Diesel principaux = main diesel engines. — Filtre = Filter. — Pompe de graissage = lubricating pump. — Refrigérant = Cooler. — Réservoir d'huile = oil tank. — Soupape de sûreté = safety valve.

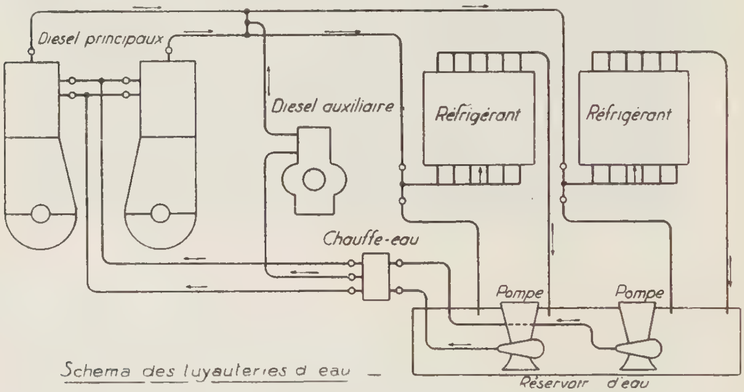


Fig. 19. — Diagram showing water piping.

Note. — Diesel auxiliaire = auxiliary diesel engine. — Chauffe-eau = water heater.

speed of the diesel auxiliaries to 1 250 r.p.m. which still allows it to develop 130 H.P. However, should one of the two auxiliary sets fail, the speed of the other set can be increased to 1 500 r.p.m., so that the latter set can, on its own, continue the feeding of all the engine auxiliaries.

The auxiliary sets are mounted on a special frame onto which rollers can be fitted to allow the sets to be very easily withdrawn through a side panel. The diesel engine of each auxiliary set is fed by oil stored in a special 425-l. (93 Br. gall.) tank.

Diagrams of the oil and water circuits of a unit are shown in figures 18 and 19. These fluids are cooled by two lateral cooling sets, each consisting of two rows of 8 elements; the outer elements in direct contact with the cold air are used for oil, the inner for water. One of the 8 outer elements of a side row cools the lubricating oil of the auxiliary diesel. Two vertical motor-pump sets of 1 200 l. (42 cu. ft.) per minute capacity feed in parallel the three engines of the unit.

The preheating of the main diesel engines is by circulating the cooling wa-

ter of the auxiliary diesel engine in them after it has been heated itself by heating resistances connected to the auxiliary generator. The heating of the cooling water can also be carried out by a steam jet from an outside source.

Electrical equipment.

In order that the four generator sets may be completely independent as on the heat engine side, the locomotive carries 4 identical and distinct electric traction equipments. All the latter machines were constructed in the Givors Works of the Fives-Lille Company.

Each of the main generators supplies, in parallel, half of each of the three double traction motors of the corresponding unit, the two armatures of each motor thus being connected to different generators. Should a generator set be out of order, the power obtainable and the maximum tractive effort is reduced by 25 %.

The 8-pole self-ventilated main generators have only one bearing and the hollow shaft of the armature is bolted to the end of the crank shaft. These machines have a separate exciting winding fed by an exciter at the end of the shaft (1) and a series winding with demagnetising effect when running, which also excites the generator working as a series motor fed by the battery, on starting the diesel engine.

The 4-pole self-ventilated traction motors (2) have series wound excitation without reduction of the field.

The following table gives the chief characteristics of the main generators and traction motors :

—	Main generators.	Traction motors.
Continuous rating :		
Speed (r.p.m.)	700	1 260 (at 86 km. = 55 miles per hour)
Power	670 kw. at terminals.	2 × 280 H.P. on the shaft.
Terminal voltage (V)	640	640
Intensity (A)	1 050	2 × 350
Maximum heating (3)	90° C. (194° F.)	117° C. (243° F.)
Efficiency (%)	93.3 (4)	93 without gears.
Hourly rating :		
Speed (r.p.m.)	700	1 200 (at 82 km. = 51 miles per hour).
Power	770 kw. at terminals.	2 × 320 H.P. on the shaft.
Terminal voltage (V)	650	640
Intensity (A)	1 200	400
Maximum heating (3)	100° C. (212° F.)	114° C. (237° F.)
Efficiency (%)	92.7 (4)	92.5 without gears.

(1) These machines (150 V., 120 A.) are sufficiently powerful to enable one of them to excite the two main generators of the unit should the other fail. A panel with connecting strips allows the necessary connections to be made rapidly.

(2) The intake of air for ventilation is at the sides of the locomotive, whence it passes to the engines through the box girders bracing the underframe.

(3) The C. M. T. 18 regulations permit 120° C. (248° F.) for armatures and inductors at the continuous rating (by variation of resistance).

(4) Including the losses due to the bearings and ventilation of the exciter.

There is no apparatus in existence which opens the traction circuits under load (fig. 20); these are only opened under no load by the return to the zero position of the reversing gear, controlled electro-pneumatically, after de-excitation of the main generator.

In order to regulate the power supplied by the diesel engines, the speed of which is kept constant for each step by the action of its speed regulator, the separate excitation of the exciter is acted upon by means of a rheostat inserted in the exciting circuit connected to the low tension circuits (150 volts).

The automatic regulation of the power supplied by each generator set is carried out by a Cuenod excitation regulator which is controlled by the rods governing the injector pumps.

The lever controlling the regulation of the power can be placed on 20 steps which cor-

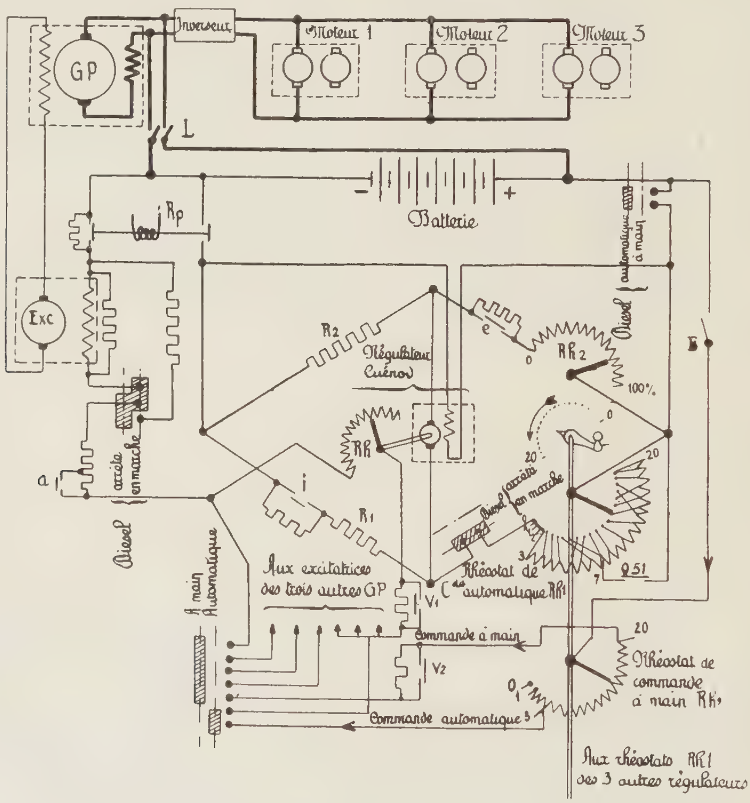


Fig. 20.

Explanation of French terms :

A main = manual. — Aux excitatrices des trois autres GP = to the exciters of the three other main generators. — Aux rhéostats Rh_1 des 3 autres régulateurs = to the rheostats Rh_1 of the 3 other regulators. — Commande à main = manual control. — Commande automatique = automatic control. — Diesel arrêté (en marche) = diesel stopped (running). — Inverseur = reverser. — Moteur = motor. — Regulateur Cuénod = Cuénod regulator. — Rhéostat de c^{de} à main — manual control rheostat. — Rhéostat de c^{de} automatique = automatic control rheostat.

respond to the following speeds of the diesel engines :—

Steps 1 to 7 : 550/500 r.p.m.
» 8 to 16 : 650/620 »
» 17 to 20 : 700 » approximately.

With the first two steps, which are used for shunting and starting, the automatic regulating system does not come into action, and the excitation of the generators, in addition to being very low, is regulated by hand. Each of the other steps corresponds to a functioning of the generator sets at a power maintained constant automatically, this power being the higher the farther from zero the steps occupied by the hand lever are located (1). For this purpose, the lever works four rheostats Rh_1 (one per generator set) each constituting a branch of a Wheatstone bridge, the three other branches of which include fixed resistances R_1 and R_2 and a rheostat Rh_2 with 100 steps worked by the rods governing the injection pumps of the diesel engine. The bridge diagonal is made by the armature of the Cuenod regulator servo-motor which drives in either direction according to the direction of the current passing through the armature, a carbon contact running on the 100 steps of the exciting rheostat Rh of the exciter (fig. 21). For the servo-motor to be stopped, the resistances of the rheostats worked by the control lever and by the rods of the diesel injection pumps must be in a given relation; consequently when the lever is kept on a step, the Cuenod regulator controls the excitation of the exciter, that is to say, the power absorbed by the main generator, so that the Diesel works at constant injection and, therefore, at constant power. It can be seen that the diesel engines because of this cannot be overloaded, even in the case of one or more cylinders working defectively.

By working an « automatic running — manual running » lever on the driving panel, the driver can, if necessary, cut out the automatic regulation and control the exciters by means of the acceleration lever which governs a single rheostat Rh' controlling the four exciters. The driver must then see that the diesel engines are not overloaded, by watching the four remote indicators, showing the rate of injection, which are arranged in front of him in the driving compartments.

(1) Steps 16 and 20 correspond respectively to 920 H. P. and to the hourly rating (1 050 H. P.) of the diesel engines.

The equipment is protected by maximum-intensity relays and special differential relays, which, in case of skidding (relative variation of the load on any two motors), cause a reduction of the excitation of the main generators concerned. In addition, immediately the locomotive commences to move, a small oil pump, driven by one of the axles, locks the reverser and prevents its being operated in the direction opposite so that in which the locomotive is moving.

If the temperature of the exhaust gases from the main diesel engines becomes excessive, due, for example, to a defect in the turbo-blowers, the power taken by the main generators is automatically restricted.

Each unit carries a battery of cadmium-nickel accumulators composed of 90 SAFT elements, having a capacity of 218 Ah., normally discharging in 5 hours. This battery, charged by the corresponding auxiliary set, starts the generator sets and feeds the auxiliary motors of the unit, the operating and control circuits being fed by the battery of the unit occupied by the driver. As previously mentioned, should a set of auxiliary diesel engines become defective, the two batteries can be charged and all the auxiliaries fed by the set still in service.

Driving compartment.

The driving cabs are arranged in a similar manner to those of locomotive 262-BD-1, in order to assist the staff in

carrying out their duties, especially in regard to the relative positions of the hand-levers, control buttons, pilot lamps, etc. There are five driving levers :

— two levers, for starting and stopping the main diesel engines, each of which governs simultaneously two engines not of the same unit;

— one acceleration lever which, as explained previously, regulates the running of the locomotive;

— one « automatic running-manual running » lever;

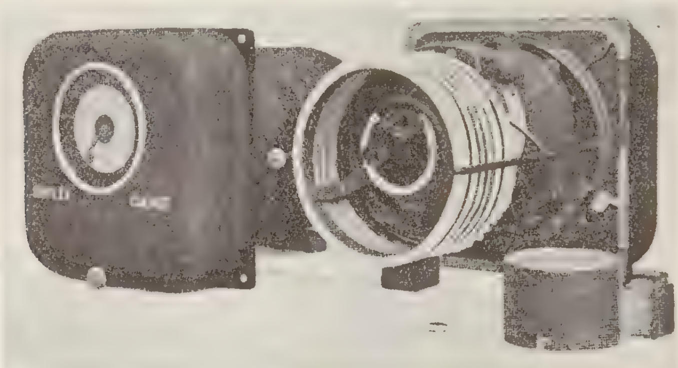


Fig. 21.

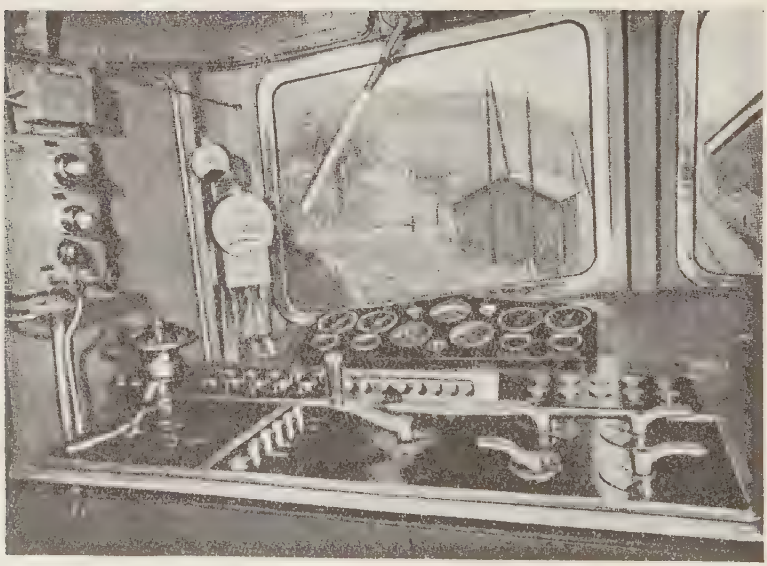


Fig. 22.

· one removable reversing lever which, when removed, locks the driving panel and isolates all the control circuits.

In addition to the tachometers of the main diesel engines, the driver has in front of him indicators showing the position of the rods governing the injection pumps for use when under manual control.

Table showing the comparative weights of the main components of the two locomotives.

262-AD-1.

Underframe, body, axles and wheels, suspension, tanks . .			104 500 kgr. *(230 380 lb.)*
Brakes (rigging, compressors, reservoirs and compressed air details)			6 500 kgr. *(14 330 lb.)*
Main generator sets :	diesel engines .	26 660 kgr. *(58 780 lb.)*	55 000 kgr. *(121 250 lb.)*
	generators . .	20 840 kgr. *(45 940 lb.)*	
	framing . . .	7 500 kgr. *(16 530 lb.)*	
Auxiliary generator sets with base frames.			4 300 kgr. *(9 480 lb.)*
Diesel auxiliaries (cooling equipment, pumps, ventilators). .			7 050 kgr. *(15 540 lb.)*
Battery of accumulators . . .			4 000 kgr. *(8 820 lb.)*
Traction motors (without gears).			23 650 kgr. *(52 140 lb.)*
Electric apparatus and wiring .			6 000 kgr. *(13 230 lb.)*
Complement of	fuel-oil. . .		6 850 kgr. *(15 100 lb.)*
	gas-oil . . .		750 kgr. *(1 650 lb.)*
	lubricating oil . . .		1 000 kgr. *(2 200 lb.)*
	water . . .		2 400 kgr. *(5 290 lb.)*
	sand . . .		1 200 kgr. *(2 645 lb.)*
Miscellaneous			1 300 kgr. *(2 865 lb.)*
	Total . . .		224 500 kgr. *(494 920 lb.)*

262-BD-1.

Underframe, body, axles and wheels, suspension, tanks . .			101 350 kgr. *(223 440 lb.)*
Brakes (rigging, compressors, reservoirs and compressed air details)			8 100 kgr. *(17 860 lb.)*
Main generator sets :	diesel engines .	41 200 kgr. *(90 830 lb.)*	61 200 kgr. *(134 920 lb.)*
	generators . .	16 000 kgr. *(35 270 lb.)*	
	framing . . .	4 000 kgr. *(8 820 lb.)*	
...			
Diesel auxiliaries (cooling equipment, pumps, ventilators). .			9 825 kgr. *(21 660 lb.)*
Battery of accumulators . . .			3 170 kgr. *(6 990 lb.)*
Traction motors (without gears).			24 660 kgr. *(54 360 lb.)*
Electric apparatus and wiring .			6 350 kgr. *(14 000 lb.)*
Complement of	fuel-oil. . .		7 000 kgr. *(15 430 lb.)*
	...		
	lubricating oil . . .		1 440 kgr. *(3 170 lb.)*
	water . . .		3 280 kgr. *(7 230 lb.)*
	sand . . .		400 kgr. *(880 lb.)*
Miscellaneous			1 225 kgr. *(2 700 lb.)*
	Total (1) . . .		228 000 kgr. *(502 640 lb.)*

(1) This figure is 2 400 kgr. *(5 290 lb.)* higher than that given in the first part of this paper, this being due to subsequent alterations.

[625. 2 & 656. 221]

The weight factor in train resistance and its influence on the economic value of vehicles made of light-weight metals,

by Regierungsbaumeister a. D. Fritz REIDEMEISTER, V.D.I., Berlin.

(Zeitschrift des Vereines Deutscher Ingenieure).

The energy required to haul railway rolling stock depends very largely on the weight of the vehicles. The importance of the weight factor increases the more often the vehicle has to be set in motion and the more inclines and curves are met with. Working out the traction costs, in terms of the weight, for a D (corridor) express train journey, on a route of the average kind found on the German State Railways, shows that the increased initial costs due to the employment of light-weight metals are completely covered by the economies realised as a result of the reduction in weight.

Advantages of reducing the weight.

Reducing weight in the design and construction of rolling stock is being more and more generally recognised as a legitimate requirement, representing, as it does, a saving in materials to begin with, and continuous savings in fuel and track maintenance charges, with less wear and tear of materials used in the running gear of the vehicles, particularly rubber. If the weight reduction allows at the same time of a smaller consumption of raw materials, such as rubber or steel, of which there is an insufficient supply in Germany, it has a further economic advantage; this applies particularly to the use of home produced light-weight metals, such as aluminium and magnesium.

Any reduction in rolling stock weight, however unimportant, is accompanied by some increase in cost. If the vehicle concerned serves to convey passengers or goods against payment, its proprietor will judge the value of the reduction by the increased receipts it enables him to obtain, for example, by being able to add a row of seats in his bus without having to strengthen the chassis, or to attach another truck to his locomotive, while leaving unaltered the work required from the boiler. A far less favourable balance would be obtained, however, if the saving in running costs due to the diminished weight were to be considered without reference to increased receipts. We propose, in what follows, to examine the question of how far the reduction of running costs justifies the additional first cost of using light-weight metal construction in an express corridor carriage.

The principal objection constantly brought forward against such means of weight reduction is that, apart from the increase in first cost, the resistance met with in running at the high speeds now usual is much more dependent on air resistance than on weight, a point of view explainable by the fact that it is frequently the resistance to running at a steady speed on level straight track that is considered, i.e. at high speeds.

In the first part of the following investigation the running resistance depending on weight is separated from that depending on the shape of the vehicle, that is to say the part due to air resistance. It is generally recognised

that the considerable saving in weight obtained in the latest types of vehicle as compared with the steel and wooden types by reducing the weight of the internal fittings and accessories, by means of *welded steel* construction and the partial use of high-grade steels, is economically justifiable. As this may be regarded in many quarters as sufficient, it is proposed to inquire whether the increased initial cost required for a further reduction in weight, of for example, 20 %, which is considered obtainable with light-metal construction, is justified, that is to say if the increase in cost of materials can be covered by savings in running costs.

The proportion in which light-weight metal is used and the consequent saving in weight is in itself practically of no economic significance, since saving in weight, saving in fuel and increased initial cost [1] are substantially proportional to each other. The saving in weight now suggested of 20 %, obtained by using a material 66 % lighter, is not merely desirable but realisable in practice, as may be shown by citing the example of one of the Pullman Company's corridor coaches. Being 2.80 m. (9' 2 1/4") longer and somewhat wider than the European corridor stock, this has 17 % more space inside. Subtracting the weight of a special air conditioning plant weighing 3.1 tons this vehicle is, in spite of its larger dimensions and kitchen equipment, about 21 % lighter than the latest European welded all-steel express corridor carriage.

It is riveted practically throughout, however, but it would now be possible to obtain still further saving in weight, especially if light-metal welding can be successfully applied to rolling stock construction.

Train resistance on level straight track.

The resistance offered by a railway vehicle on a straight and level track is composed of the following elements [2]:

1. The running resistance properly speaking, which is independent of the speed, including friction in the bearings and between wheel and rail;

2. The resistance due to shocks on the track, a component increasing proportionally to the speed;

3. The air resistance, which varies approximately as the square of the speed [3].

With the aid of certain co-efficients, such as have, for example, been given by FRANK, STRAHL, SAUTHOFF, and VOGELPOHL for given vehicles, this total resistance can be calculated in terms of the speed. The following formula of SAUTHOFF

$$W_w = G \left[a + b \cdot V_F + 0.0048 \frac{1}{G} (n + 2.7) \, F V^2{}_R \right] \quad . \; . \; . \; . \; . \; . \quad (1)$$

shows that the two first components of the resistance are dependent on the weight, while the third, the air resistance, depends only on the shape of the vehicle. In this formula : W_w is the resistance of the vehicles in kgr., G is their weight in metric tons, a is the runnung resistance proper = 1.9 kgr./t., b the co-efficient of the resistance due to shocks on the track = 0.0025 kgr./h./tkm., V_f the running speed in km. per hour, n the number of vehicles, F the equivalent area in m², and V the relative air velocity in km. per hour.

The resistance offered by the vehicles per unit of weight $W_w = \frac{W_w}{G}$ is, for

(1) F. REIDEMEISTER, *Organ Fortsch. Eisenbahnwesens*, Vol. 90 (1935), page 35.

(2) For further details, see G. VOGELPOHL, *Z. V. D. I.*, Vol. 79 (1935), page 851.

(3) See also G. VOGELPOHL, *Forschung Ing. Wes.*, Vol. 6 (1935), page 217.

example, according to equation (1), 4.4 kgr./t., (9.8 lb. per Engl. ton) for a speed V_F of 85 km. (52.8 miles) per hour, a relative air velocity V_R of 100 km. (62 miles) per hour and a ten-coach train weighing $G = 400$ t. (393.6 Engl. tons), with an equivalent area F of 1.45 m² (15.6 sq. ft.).

Gradient and curve resistance.

In practice the above-mentioned resistance factors are supplemented by others due to the nature of the line and operating conditions, such as resistances caused by gradients, curves and acceleration, themselves likewise dependent on the weight of the vehicles.

The influence of gradients and curves on the total resistance is generally underestimated, it being overlooked, for example, that 70 % of the German State Railway system (4) is formed of gradients, and 30 % is curved. The important part played by the weight of vehicles on gradients has been very well brought out in an article by L. K. SILLCOX (5). The effect of the weight on various gradients is shown in figure 1. It is to be noted that the resistance offered by a 20-ton vehicle on a 1 in 71 gradient is 3 1/2 times what it is on the level, while for a 70-ton vehicle the increase is 6.4 times. The steepest gradient met with on the German Reichsbahn main lines is 1 in 25. Tests in this direction with road motor vehicles showed that, even with a light-weight touring car the measured fuel consumption on, for example, a 1 in 11 gradient rose from 0.081 litre per tonne-kilometre to 0.213, or in other words was nearly trebled (6).

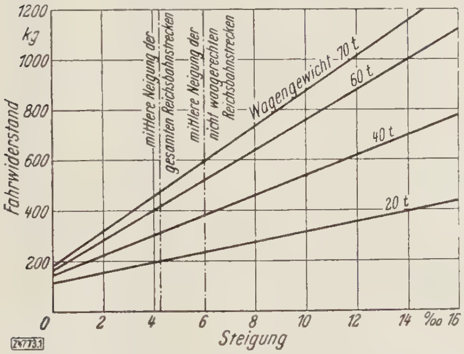


Fig. 1. — The dependence of the running resistance of railway vehicles on their weight, when on gradients.

Explanation of German terms:

Fahrwiderstand = running resistance. — Mittlere Neigung der gesamten Reichsbahn = average gradient on the whole Reichsbahn. — Mittlere Neigung der nicht waagerechten... = average gradient on non-level lines of the Reichsbahn. — Steigung = gradient. — Wagengewicht = weight of vehicle.

On the Reichsbahn, the average gradient on the lines in hilly country is 1 in 167, the average radius of the curved sections $r = 700$ m. (35 chains). If the gradient figure is spread over the remaining 30 % of level line an average of 1 in 238 is obtained for the whole of the system. As on a down gradient there is no gradient resistance to be overcome, only 50 % of the average gradient, or 1 in 476, corresponding to a rising gradient resistance of $w_s = 2.1$ kgr./t. (7.56 lb. per Engl. ton), has been assumed in calculating the vehicle resistance.

For the 30 % of curved track the curve resistance would be, according to v. RÖCKL (7)

$$w_k = \frac{650}{r - 55} = 1 \text{ kgr./t, or}$$

2.24 lb. per Engl. ton approx., which gives an average value for the whole German Reichsbahn system of about 0.3 kgr./t. (0.67 lb. per Engl. ton). As the

(4) In all numerical data in this article referring to the German State Railways or Germany as a whole, the figures for Austria are not included. Owing to the hilly nature of the Austrian lines, the proportion of inclined and curved lines would be further increased by including them.

(5) L. K. SILLCOX, *Railway Age*, Vol. 100 (1936), page 426.

(6) HALLER, *Verkehrstechn.*, Vol. 17 (1936), page 523, and Vol. 18 (1937), page 212.

(7) F. MEINEKE, *Kurzes Lehrbuch des Dampflokomotivbaus* (Short textbook on locomotive construction), Berlin, 1931, page 8.

steepest and most heavily curved sections are only traversed to a limited extent by D (corridor) trains, only 60 per cent of the system-average for gradient resistance w_s and curve resistance w_k, is taken in the present example for such a train; therefore $w_s = 1.26$ kgr./t. (2.82 lb. per Engl. ton), and $w_k = 0.18$ kgr./t. (0.4 lb. per Engl. ton). Thus the resistance offered by the vehicle at a steady speed at average values for gradient and curvature is

$$w_{w \text{ steady}} = w_w + w_s + w_k = 4.4 + 1.26 + 0.18 = 5.84 \text{ kgr./t. (13.1 lb. per Engl. ton).}$$

Resistance due to acceleration.

The factors for resistance to movement hitherto considered relate exclusively to movement at a steady speed. Over the distance covered while accelerating to that figure, which is about 7 km. (4.35 miles) with D trains, the resistance to acceleration w_b has to be added, and this amounts to $\frac{1000}{9.81} \times 0.08$ = about 8 kgr./t. (17.9 lb. per Engl. ton) for an acceleration of 0.08 m. (0.26 ft.) per sec. per sec.

The cost incurred in accelerating a vehicle depends on the work performed in doing it :

$$A = \frac{Q\,l\,w_b}{270} \text{ (H.P.-h.)}$$

where Q = weight of the train, and l the length of the section over which the acceleration occurs.

The work done in accelerating the hauled part of a 400-t. train over a length of 7 km., the resistance to the acceleration being taken as $w_r = 8$ kgr.-t., is given by

$$A = \frac{400 \times 7 \times 8}{270} = 83 \text{ H.P.-h.}$$

which, at the cost worked out below of 2.5 Rpf. per H.P.-hour gives a figure of 2 Rm. for accelerating from rest up to 120 km. (75 miles) per hour.

That such a low value may be given to this figure is demonstrated by the calculations made in Berlin in connection with the electrification of the Wannsee line, which showed that a full length all-steel train making a run of 18.6 km. (11.55 miles) on a suburban section with nine stops costs 49.88 Rm. for current, or 33.32 Rm. for a non-stop run, each acceleration period thus costing 1.84 Rm. An indication of the savings that can be realised by adopting light-weight construction for suburban services is shown by the fact that at each station on the Wannsee line, with a service only every 10 minutes there are 90 000 train starts annually. It is also interesting to consider the work involved in accelerating a train on the Berlin Ringbahn (Circle Ry.). There are 31 stops to start away from on a route length of 43 km. (26.7 miles), or, in 110 000 km. (68 350 miles) covered annually, some 80 000 departures per train (8). A saving of 20 % in dead weight means 15 % reduction in the weight of an average loaded carriage and so reduces the cost of accelerating it by 15 % = 0.28 Rm. This means a yearly saving in acceleration costs of 22 400 Rm. per full-length train, which suffices, through current saving alone, to cover in 7 to 8 years the extra first cost for the light-weight construction, which is 162 000 Rm. (54 tons weight saved × 3 000 Rm. per ton).

Some American railway companies are paying special attention to the cost of accelerating their trains (9), which is understandable when the still great-

(8) G. WAGNER, *Glasers Annalen*, Vol. 109 (1931), page 108.

(9) The resistance to acceleration is markedly greater as a consequence of a greater friction in the bearings. See a comprehensive account by G. VOGELPOHL, *Z. D. V. I.*, Vol. 79 (1935), page 851, especially page 853.

er weights of American trains are borne in mind. For example, the Missouri-Kansas-Texas Company puts notices in its signal boxes reminding the signalmen that each unnecessary stopping of a train costs $ 2.5. The Atchison-Topeka & Santa Fe Company takes as an average figure for all classes of train 8.40 Rm., and the Illinois Central 2.10 Rm. as the cost of accelerating an eleven-car express train on a level dry rail up to a speed of 80 km. (50 miles) per hour [10]. The sources of error contained in these particulars, involved in arriving at fuel and water consumption, are avoided with electric locomotives by taking direct readings. Such readings showed that for accelerating trains of from seven to twelve coaches (540 to 915 metric = 531.4 to 900.1 Engl. tons) up to 112 km. (69.6 miles) per hour the current consumption was 200 to 270 kWh [11]. At a cost for current of only 0.02 Rm. per kWh., the acceleration costs come to between 4 and 6 Rm., so that in comparison with the very markedly heavier American trains the costs for the German D trains, of 2 Rm., appear rather on the low than on the high side. In order to arrive at the number of accelerations to be considered we will not start from the fact that there is a station to each 4.5 km. (2.8 miles) of line of the German Reichsbahn (about 1 200 stations to 53 000 km. = 32 930 miles), as this would mean that a train would regularly start from rest 22 times in every 100 km. (62 miles), but here we will consider D trains only. The time tables show the average distance between stops for the ordinary D trains to be 40 km. (25 miles) on the Berlin-Munich route, 32 km. (20 miles) on the Berlin-Cologne route, and 30 km. (18.6 miles) on the Berlin-Basle run, which means that such trains stop regularly on the average 2.5 to 4 times per 100 km.; in this article we will take the former figure.

If the working time tables for the sections over which the D trains run are examined they will be seen to show, in addition to the regular stops, a number of speed restrictions for bridges, running through points or round curves, through stations, etc., after which a train must again be accelerated up to its working speed. To this must be added periods of acceleration after gradients and permanent way slacks, or unusual delays, such as stopping or slowing down for adverse signals. Further, if it is borne in mind that when the working speed of a train is high the acceleration following a speed reduction almost equals that following a stop, and if this is conservatively taken as only an additional half period of acceleration per 100 km. it can be estimated that in each 100 km. there occur the equivalent of 3 accelerations. Consequently, that distance we can consider as made up of $3 \times 7 = 21$ km. corresponding with acceleration periods, 5 km. running with closed regulator and braking distances, and 74 km. of running at the working speed. If the resistance to acceleration w_f of 8 kgr./t., belonging to 21 km. out of the 100 km., is spread over the total distance the result is an average constantly effective acceleration resistance of about 1.7 kgr./t. (3.8 lb. per ton). Figure 2 shows this in conjunction with the total running resistance of the vehicles. In this figure the curve *a*, representing the vehicle resistance for a train of ten vehicles according to SAUTHOFF, is separated in curve *b* into air resistance and resistance proportional to the weight, according to equation 1. The curves *c* and *d* represent the resistance, according to SAUTHOFF, for level and straight track, completed by the amount due to average gradient and curvature, and the total resistance so obtained, which only applies to steady running,

(10) *Railway Age*, Vol. 100 (1936), p. 523.
(11) C. A. TAYLOR, *Railway Age*, Vol. 100 (1936), page 465.

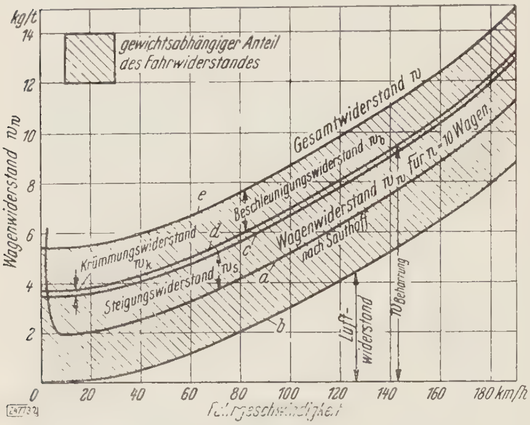


Fig. 2. — Vehicle resistances w_w according to SAUTHOFF, divided into air resistance and weight resistance, and supplemented by gradient, curvature and acceleration resistances for 40-ton corridor carriages, with 4.2 m. (13.8 ft.) per sec. head wind.

a) Vehicle resistance for a ten-carriage train.
b) Air resistance.
c) Vehicle resistance on an average gradient.
d) Vehicle resistance on an average gradient and curve.
e) Total resistance.

Explanation of German terms:

Beharrung = running at steady speed. — Beschleunigungswiderstand = acceleration resistance. — Fahrgeschwindigkeit = speed. — Krümmungswiderstand = curve resistance. — Gewichtsabhängiger Anteil des Fahrwiderstandes = proportion of running resistance varying as the weight. — Luftwiderstand = air resistance. — Steigungswiderstand = gradient resistance. — Wagenwiderstand = resistance offered by vehicle. — Wagenwiderstand für n = 10 Wagen, nach Sauthoff = vehicle resistance for n = 10 coaches, according to Sauthoff.

developed into the total values shown by curve *e* by the addition of an average figure for acceleration resistance. The hatched portion of the diagram represents the proportion of the resistance dependent on the weight.

Traction costs and economies.

The coal consumption for the express locomotives at present in service on the German Reichsbahn amounts, at a speed of 100 km. (62 miles) an hour for the 01 class standard type, to 1.27 kgr. (2.8 lb.) per H.P.-hour, and for the 03 class standard type to 1.33 kgr. (2.93 lb.) per H.P.-hour. For the S. 3/6 and S. 10 classes the figures are 1.46 and 1.44 kgr. (3.21 and 3.17 lb.) per H.P.-hour respectively [12].

If one takes, for purposes of further calculation, the lowest figure of 1.27 kgr./H.P.-hr., this gives, the price of coal being taken at 20 to 23 Rm. per ton, costs varying from 2.5 to 3.1 Rpf. per H.P.-hour. The former value will be used here. The cost of running 74 km. out of each 100 km. at a steady speed is

$$\frac{400 \times 74 \times 5.84}{270} = 640 \text{ H.P.-hrs.} \times 2.5 = 16 \text{ Rm.}$$

which equals 16 Rm. at a price of 2.5 Rpf. per H.P.-hour. Adding the 6 Rm. for the three accelerations from rest gives 22 Rm. as running cost per 100 km. These figures agree in magnitude with those which LEIBBRAND gives as operating costs for the German Reichsbahn [13]. If 30 % be subtracted for the propelling of the locomotive itself from this figure of 30 Rm. running costs per 100 km. for an express train travelling at 85 km., we get 21 Rm. for hauling the coaches 100 km. This figure of 30 Rm. running costs appears surprisingly low — a few years previously TECKLENBURG had put it at 43 Rm. per 100 km. [14] — if we consider that in the calculations already made above regarding, for example, steam consumption, for costs per 1 H.P.-h., the lowest figures were used throughout. The higher the running costs, the greater will be the savings for equal percentages. We have nevertheless taken the rates of expenditure published by the Reichsbahn as the basis of our investigation hereafter.

(12) According to « 100 Jahre deutsche Eisenbahnen » (A Century of German Railway development), Berlin, 1935, page 151.

(13) M. LEIBBRAND, *Z. D. V. I.*, Vol. 80 (1936), page 349.

(14) K. TECKLENBURG, *Verkehrstechn. Woche*, Vol. 22 (1928), page 519, and especially page 525.

Fuel costs vary as the total resistance to motion, which, according to figure 2, is composed as follows for a speed of 85 km. (52.8 miles) an hour :

$$w_{tot.} = w_w + w_s + w_k + w_b = 4.4 + 1.26 + 0.18 + 1.7 = 7.54 \text{ kgr./t. (15.78 lb. per ton)}.$$

Of this value 5.5 kgr./t. (12.32 lb. per ton), or 72 %, are dependent on the weight. Therefore a 20 % reduction in the components varying as the weight means a fuel saving for the vehicle under consideration of 0.2 × 72 = 15 % approx. All vehicles, which under similar circumstances start more than three times per 100 km. (62 miles), or accelerate at a greater rate than 0.08 m. (0.26 ft. per sec. per sec.), or, in consequence of lower speed or streamlined form, make out a larger proportion of resistance dependent on their weight, show correspondingly greater reduction in fuel costs for weight saved than does the ordinary fast train, For example, with the light-metal trains of the Berlin Metropolitan Ry., the saving in cost of current has been found to correspond exactly with the reduction in weight.

Il will, moreover, be conceded that the example selected above of a D train is a case where there is not much prospect of making noticeable savings by cutting down weight. On suburban lines, for instance, where, on account of the frequent starts, almost all the work of propelling the train is done during the acceleration periods, a reduction in weight operates to much better effect, as it also does with self-propelled vehicles, especially railcars. It is true that with fast vehicles travelling singly the relation between air resistance and resistance due to weight, seen in Sauthoff's curves, is essentially different from that for a complete train, in which the rear vehicles are shielded from the wind by those in front; on the other hand with a single vehicle, in contrast to one in a train, there is the possibility of streamlining the ends so that, as the effect of air resistance decreases, the influence of the weight on the total running resistance increases. Furthermore, calculations show that, for other types of train, according to the method of operating them, greater savings as a result of weight reduction are obtained than with D trains, as is already evidenced by the fact that the power consumption, and hence the saving per tonne-kilometre, for a D train and a Berlin Metropolitan train, rises in a 35 to 55, or 1 to 1.56 ratio.

In addition to the savings in the costs of traction, the rolling stock maintenance and permanent way costs are also lower with lighter vehicles. According to TAYLOR, rolling stock maintenance costs (brake shoes, wheels sets, etc.) are dependent on the weight of the vehicles to the extent of 60 %, and permanent way costs to the extent of 50 %. Other American information puts the wear and tear on the permanent way as proportional to the train weight and the square of the speed. E. V. PANNEL gives a possible saving in rolling stock upkeep of 0.30 Rm. for each kgr. saved on a 30-ton vehicle [15], which, for the weight reduction of 8 tons assumed here, would make an annual saving of 2 400 Rm. Taking average values from these particulars, a possible saving of 11.35 Rm. per 100 km. has been worked out for Table 1, on the basis of the running costs given by LEIBBRAND [13]. As a train of eight vehicles is assumed, the saving per vehicle is only one eighth of this, or 1.42 Rm. per 100 km. (2.28 Rm. per 100 miles); certain less important factors, difficult to arrive at, and which depend on the weight, such as coaling the locomotives, are not taken into consideration.

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(15) E. V. PANNEL, *Railway Gazette*, Vol. 64 (1936), page 613.

TABLE 1. — **Savings in traction costs for an eight-car corridor train with a 20 % weight reduction.**

Item of cost.	Cost price. Rm.	Proportion varying as the weight. %	Saving due to a 20 % weight reduction.	
			%	Rm. per 100 km. (62 miles)
Maintenance of permanent way . .	24	60	12	2.90
Renewal of permanent way	10	50	10	1.—
Fuel, lubricants, etc., for traction of :				
vehicles	21	72	15	3.15
locomotive itself	9	—	—	—
Care and maintenance of locomotive.	36	—	—	—
Locomotive renewal	12	—	—	—
Maintenance of rolling stock . . .	33	65	13	4.30
Renewal of do. . . .	25	—	—	—
Staff costs	32	—	—	—
	202 (15)	—	—	11.35

The annual saving in running costs depends on the mileage run. The remarkable performances of the American light-weight trains is partly due to the extent of their railway systems; for example, the light-weight *Union Pacific* Railway trains cover 1 500 km. (930 miles) in a day, the twin *Zephyr* trains of stainless steel, 1 400 km. (870 miles) daily, and the *Mark Twain Zephyr*, 710 km. (440 miles). Even, however, on shorter runs it is possible to get excellent service out of the rolling stock. The light-weight metal *Comet* train runs six times daily between Boston and Providence, covering 850 km. (530 miles) daily. The Baltimore and Ohio *Royal Blue* high-speed train, composed of eight light-weight metal carriages, runs daily more than 900 km. (560 miles) between New York and Washington [16]. According to LEIBBRAND, the express railcars of the German Reichsbahn give a daily service of considerably over 1 000 km. (620 miles) [13], the ordinary railcars reaching 500 km. (310 miles). The Berlin Metropolitan carriages run 110 000 km. (68 350 miles) in a year [8], and the long-distance corridor expresses of the Reichsbahn run up to 1 200 km. (750 miles) daily. Generally speaking the running of corridor coaches on that system is so arranged that the 100 000 km. (62 000 miles) run between two overhauls are, as far as possible, accomplished within six months.

It is assumed that the light metal vehicles under consideration in this article would be run under identical arrangements. Still greater mileages are covered, according to advertisement posters issued by the German Reichsbahn, on which it is stated that a corridor carriage runs on an average 630 km. (390 miles) per day. Allowing one month for repairs and one further month as waiting or reserve time, the yearly service of a corridor carriage can be put at 180 000 km. (112 000 miles), on the basis of the above data. Reckoning 1.42 Rm. per 100 km. (62 miles) this gives an annual reduction in the running costs of about 2 600 Rm. per vehicle.

(16) *Railway Age*, Vol. 99 (1935), page 706.

The costs of weight saving by the use of light-weight metals.

Against the saving in fuel costs realised by light-metal construction, we have to set a proportionately heavy increase in initial costs. However, in the case of high-priced vehicles, especially railcars, the proportion of this increased cost of materials to the total cost is mostly very small. For example, RAGSDALE [17] states that this was only 8 % in the case of stainless steel railcars. Table 2 gives the additional costs stated by certain railway companies.

TABLE 2. — **Extra initial cost of light-metal vehicles per kgr. of weight saved.**

Railways.	Rm./kgr.
Central Railroad of New Jersey.	1.12
Pullman	1.52
Reading Co.	1.62
Chicago & North Western	1.65
Average for American suburban lines	1.69
Nord (France)	1.78
Cleveland-Ohio	1.88
Fonda-Johnstown	1.89
London-Midland & Scottish.	1.92
Indiana	1.92
French State.	2.00
Philadelphia & Western	2.07
Berlin Metropolitan	2.44
Clark Equipment Co.	2.74
Average	1.87

If, for ordinary conditions, a saving of 1.69 Rm. per kgr. (77 Rpf. per lb.) be taken [1], we cannot overlook the fact, when considering the figures for higher initial costs given by the railway companies, that in a comparison between an out-of-date type of vehicle (composite steel and wood, for example) and a recent light-metal type, the additional initial cost is often spread over a weight saving not attainable when one compares two vehicles built according to the latest standards of light-metal and steel construction respectively. As in the present investigation a corridor carriage of the latest type, built of St 52 welded steel, is being compared with a 20 % lighter metal type, it must be realised that a supplementary extra cost has to be set against this saving in weight. Instead of 1.69 Rm., double that figure, or 3.40 Rm. per kgr. (1.54 Rm. per lb.) of weight saved, is assumed in calculating, that is to say, an additional first cost for the light-metal vehicle of 24 200 Rm.

Allowing 1 220 Rm. as 5 % interest, and 584 Rm. as 3 % amortisation — 20 % as scrap value being left out of account — the higher initial costs necessitate 1 800 Rm. additional annual capital charge.

Pratical considerations.

Numerous particulars obtained in practice go to show that even if we double the initial costs for employing light-metal constructional parts, in which there has already been considerable competition among builders in this class of work, we still find that there is an excess of savings over higher first costs for an ordinary corridor carriage. If it were otherwise, the American railway companies — with their permissible high axle loads — would hardly have begun to make experiments in the use of light-weight metals for such stock. The annual saving of 2 600 Rm. on the traction costs per carriage allows not only of the usual 5 % interest on the extra first cost, with 3 % amortisation — amounting altogether to 1 800 Rm. — but in addition allows of an annual saving of 800 Rm. in running costs per carriage.

No transport undertaking, however, will regard the principal advantage of weight reduction as consisting in a saving on running costs, but will look to the technical possibilities of obtaining increased mileage for the same power consumption and set increase of receipts

(17) E. J. W. RAGSDALE, *Railway Age*, Vol. 98 (1935), page 52 and especially page 53.

against the extra initial expense, payable once only. Thus the railways will rather attach ten instead of eight vehicles to a locomotive, with the same boiler output, than make a saving in coal, or, keeping the same number of vehicles, raise the speed of the train, especially if they are in competition with other means of transport. The acceleration in the turn-round of vehicles so obtained brings savings in motive power user and rolling stock. LEIBBRAND ([13]) states that raising the speed of passenger trains on the German Reichsbahn from 45 to 50 km. (28 to 31 miles) represented an annual saving of 22 million Rm. He draws the following conclusion from his figures : « Train weight per passenger must be cut down and the turn-round of the carriages markedly accelerated ».

A comparison between proved foreign vehicles ([18]) mentions 34 various forms of construction employing light-metal bodies, 20 of them having parts subjected to heavy stresses, such as underframes and bogies, made of aluminium alloys.

The Statistical Bureau of the Interstate Commerce Commission of the U. S. A. has issued a report on the economic results of the American light-weight metal trains, as a result of a comparative investigation ([19]). As regards the repair costs on the carriage body portion of the railcar trains, the highest figure is taken by the « Flying Yankee » stainless steel train, with 7.1 Rpf. per car-km. (11.4 Rpf. per car-mile), the lowest by the « Zephyr 9901 », of similar material, with 2.36 Rpf. per car-km. (3.80 Rpf. per car-mile). The trains made of aluminium alloys come between. The lowest average total cost for diesel railcar trains was obtained with the seven-car light-metal « City of Portland », being 170 Rpf. per train-km. (273 Rpf. per train-mile). The service imposed on this train, the whole underframe of which is in aluminium alloy, is especially heavy, as the following details show : the American continent is crossed twelve times per month, the monthly mileage run is 44 000 km. (27 350 miles), the greatest difference in altitude met with on the journey, with corresponding temperature difference, is 2 660 m. (8 230 ft.) and the saving in journey time, compared with the year 1930, is 21 hours. The average speed, with 12 stops, is 92 km. (57 miles) an hour, and the maximum speed 192 km. (119 miles an hour). The tare weight of the train is 265 tons. Thus the construction of light-metal rolling stock is a question of finance; the initial extra first cost incurred once for all will not only enable the interest on itself to be paid but also bring various further advantages.

([18]) F. REIDEMEISTER. *Aluminium*, Vol. 18 (1936), page 496.

([19]) *Railway Age*. Vol. 101 (1936), p. 274.

Summary.

A supplementary figure for the average curvature and gradients on the German Reichsbahn is added to the vehicle resistance curves of Sauthoff for a corridor train running on level and straight track. To the running resistance so calculated for a constant working speed a further figure is added to cover the resistance due to acceleration and the sum total converted into kgr. of coal and Reichsmarks. The figures so obtained correspond with the running costs published by the Reichsbahn.

It appears that the total savings outweigh the interest and amortisation charges on the higher initial costs. The traction costs and those due to permanent way and rolling stock maintenance, which vary as the weight, are put together, and the savings resulting from a 20 % reduction in weight of the vehicles, calculated.

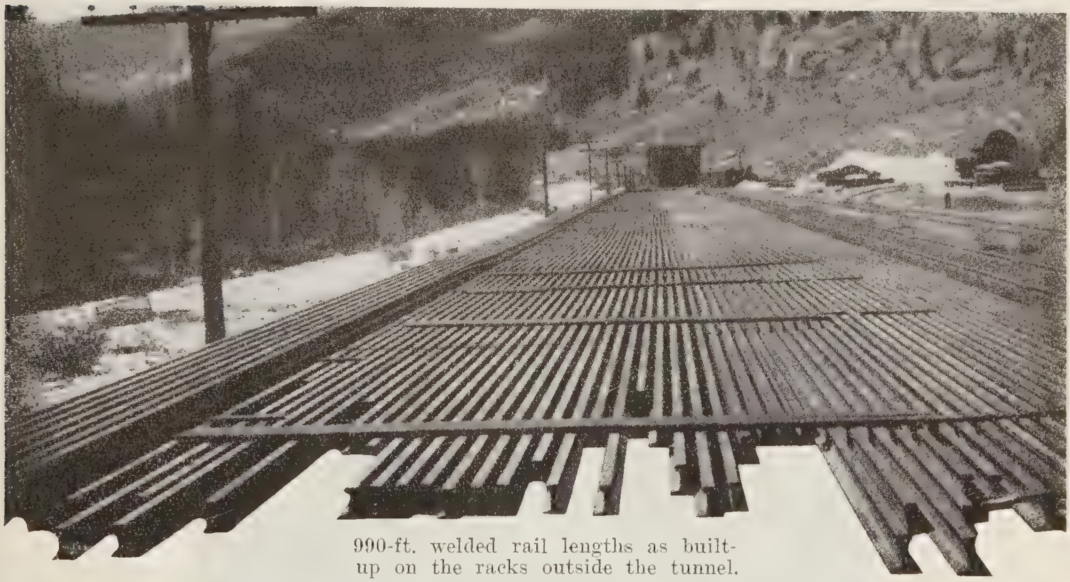
Technical and economic performance is illustrated with the aid of information from other countries and the principal difficulty is seen to reside in finding the extra initial cost when rolling stock is ordered.

[62. (01 (.75) & 625. 143 (.75)]

Fighting rail corrosion in the 6.21-mile Moffat tunnel,

by W. C. JONES,
Chief Engineer, Denver & Salt Lake Ry. Co.

(*Railway Age.*)



990-ft. welded rail lengths as built-up on the racks outside the tunnel.

This article describes an unusually serious problem of rail corrosion in the Moffat tunnel of the Denver and Salt Lake Railway, and the continuous welding of new rail laid through this bore into 6.45-mile lengths to overcome the most aggravated condition which prevailed at the rail joints. It also discusses several unusual methods investigated by the road to overcome the cinder and sulphurous acid condition which prevails within the tunnel, to which the major part of the corrosion problem is attributed.

Confronted with unusually serious corrosion of the rail and track fastenings in its Moffat tunnel, 6.21 miles long, due principally to the extreme moisture and sulphurous acid condition prevailing as the result of frequent train operation, the Denver and Salt Lake Railway has been carrying out a wide range of experiments to develop means of minimizing the corrosion, and has recently laid continuously welded rail through the tunnel to preclude the more serious conditions which have prevailed at the rail joints. In the welding work, which was done by the thermit-pressure method, rail lengths of 990 ft., built up on racks outside the tunnel, were dragged into the tunnel supported on ties employed as sleds on top of the old running rail and were then welded together to form continuous lengths 6.45 miles long, which are believed to be the longest continuous rails in the world.

In the studies which the road has

been making of methods and means to minimize the deterioration of the ferrous material of the track structure, it has given consideration to all three of the factors which have entered into the problem — normal corrosion, acid attack and electrolysis. As will be pointed out briefly later in this article, it has made tests of numerous anti-corrosion coatings; has experimented with the cathodic (electrolytic bath) method of minimizing deterioration by electrolytic action and is giving consideration to various methods of neutralizing the sulphurous acid condition prevalent in the tunnel as the result of moisture, locomotive gases and cinders.

The thermit-pressure welding equipment arranged at four joints, ready to make the welds.

Grades in tunnel.

Before discussing any of the means undertaken to off-set the serious corrosion problem presented in the tunnel, it will be well to have a general picture of the unusual physical conditions involved in the tunnel and of the special conditions which bring about this problem. The tunnel, with its east end approximately 50 miles northwest of Denver, Colo., is a single-track bore, 6.21 miles long, which passes under the Continental divide, with a maximum overburden of 2 600 ft. While projected as early as 1886 and actually located in 1902 when the railroad was determining its final location, it was not until 1923 that construction was started. The tunnel was completed early in 1928 and was opened to traffic on February 26 of that year.

The tunnel track, at elevation 9197 at the east portal, rises on a 0.3 per cent grade westerly for a distance of 2.7 miles to a summit at elevation 9239. From this point the gradient is 0.9 per cent descending for 3.51 miles to the west portal, at elevation 9 084, beyond which there is a 2 per cent descending grade to the west for a distance of approximately 9 miles.

Train movements average about 20 daily. Westbound trains, handling approximately 90 per cent empty cars, and therefore of relatively light tonnage, employ only one locomotive on the 0.3 per cent ascending grade to the summit, while eastbound traffic consists of trains

loaded for the 1 per cent grade. The 2 per cent grade west of the tunnel requires the use of helper engine service for eastbound traffic, which is continued to the summit within the tunnel. Here the helper engines are cut off and are backed down to the bottom of the 2 per cent grade.

Causes of corrosion.

One of the large factors contributing to the corrosion problem within the tunnel has been the large quantity of cinders and gases expelled from the stacks of the locomotives working at capacity. Approximately two inches of cinders are deposited on the floor of the tunnel annually from the west portal to the summit, while east of that point, with the lighter grade and absence of helper service, only about one-half as much cinders are deposited. Altogether, this deposit of cinders amounts to approximately 1 600 cu. yards annually.

Another of the important factors contributing to the corrosion within the tunnel is the condensation resulting from the contact of the air drawn in at the portals with the air of relatively high temperature within the tunnel, and also from the precipitation of moisture from the vapors and gases expelled from locomotives. The temperature at the portals varies from approximately 75 deg. above zero to approximately 45 deg. below zero, but the influence of this wide range of temperature extends only a limited distance within the tunnel. At the west end, due to the prevailing draft being eastward, assisted by electrically-operated fans with a combined capacity of 300 000 cu. ft. of air per minute, the temperature within the tunnel is affected for a distance of 1.5 miles in from the portal, while at the east end it is affected for a distanc of only approximately 0.75 miles from the portal. Within the remaining four miles of the tunnel, the temperature remains practically constant throughout the year, around 60 deg. above zero, varying not more than 5 deg. when the ventilating fans at the east portal are in full operation, drawing in fresh outside air to expel locomotive smoke and gases.

This combination of circumstances is largely responsible for much of the moisture within the tunnel. Whenever the temperature of the air drawn into and blown through the tunnel is different from the normal temperature within the tunnel, moisture condenses on the rail and track fastenings, the amount depending upon the relative temperatures involved and the moisture content of the incoming air. Furthermore, and of large importance, locomotives deposit a large volume of water from steam within the tunnel, it having been calculated that each locomotive expels by evaporation from 200 to 600 gall. of water into the atmosphere in passing through the tunnel. This moisture, together with the normal moisture of the air within the tunnel, intermixing with the locomotive stack gases, forms sulphurous acid, which, in suspension, is deposited in a thin film on the ball and web of the rail. At the same time this moisture, mixing with the cinders over the track area, produces additional sulphurous acid which attacks the base of the rail, the joint bars, the tie plates, and other track fastenings, both by straight chemical action and by stimulating electrolytic action.

The tunnel track was laid originally with 110-lb. rail in 60-ft. lengths, with joint bars and single-shoulder tie plates. The extent of the corrosion of this steel during the 10 years until it was replaced early in 1938, is seen in the fact that the rail and tie plates lost about 40 per cent of their original sections. Even more serious than the general loss of metal involved were the numerous rail failures at the joints, the result of excessive corrosion in the bolt hole areas and the impossibility of maintaining good joint conditions. As the result of

this latter factor, rail-end batter was excessive within the tunnel, averaging 0.10 in. at the time the rail was replaced.

Corrosion about the bolt holes was most severe at those holes nearest the ends of the rails, starting from the perimeter on the upper and lower sides. As the corrosion progressed, stress corrosion cracks developed, and where breaks occurred they were generally on an angle of about 45 deg. with the base, extending backward from the base near the rail end, through the bolt hole and the rail head. While the excessive corrosion which occurred here was undoubtedly responsible for the weakening of the rail, the severe impact resulting from the excessive joint batter prevailing contributed largely to the many breaks which occurred. It is significant that numerous microscopic examinations of the rail metal at breaks showed no defective metal in the rail itself which might have been responsible for the failures.

As a means of offsetting the particularly destructive effect of corrosion at the rail ends, the road, when recently considering the renewal of the tunnel rail, decided to replace it with continuously welded rail of 112-lb. R.E. section, made up of 66-ft. lengths joined by the thermit-pressure weld process. Through this method of construction it expects not only to avoid further rail failures of the type described, but also to eliminate rail-end batter and joint maintenance, while at the same time increasing the service life of the rail, improving riding conditions and reducing wear and tear on locomotives and rolling stock.

A close-up of four completed thermit joint welds, as the rails lay on the rail rack.

In the welding of the new rails to be laid within the tunnel, the individual 66-ft. lengths were welded into 990-ft. strings outside the tunnel, and were then dragged into the tunnel. All of the field welding was done on a rack located along tangent track approximately 1 200 ft. east of the east portal. This rack, which was constructed of second-hand bridge stringers and rails, was approximately 1 000 ft. long, with its top surface about 1 ft. above the top of rail of the track, and its front face approximately 4 ft. back from the near running rail.

The new rail was unloaded from cars progressively along the rear side of the

rack throughout its length, and lined up into strings for welding on that part of the rack towards the main line track. At first, space permitted the lining up of only two strings of rails at a time for welding, but later, with the reduction in the size of the storage piles of 66-ft. rails, as many as eight strings of rails were lined up at a time.

In all of the welding, the thermit-pressure method was employed, this method having been selected because of its simplicity and the economical manner in which it could be adapted to the conditions imposed. The equipment and procedure incorporated the most recent developments in the thermit-pressure method. During the actual welding work which proceeded progressively from one end of a string toward the other, from 28 to 38 welds were completed during a 10-hr. day.

Sledded into tunnel.

The sledding method of moving the long rail lengths into the tunnel proved not only relatively simple but highly effective. In carrying this out, two of the 990-ft. welded lengths were lined sidewise from the rack onto a series of second-hand white oak ties laid across the existing main track rails at intervals of approximately 40 ft. In position on the sled ties, spaced about 3 ft. apart, the individual strings were spiked at each tie, and, in addition, were secured at each tie by rail anti-creepers so that the rails and ties would move as a unit when being dragged into the tunnel.

Thus lined up, the pairs of long rails were pulled into the tunnel by a locomotive attached to their forward ends by means of a 1 1/8-in. steel cable. The cable was secured to the rails by means of a spreader yoke, which was given a hold through the holes near the rail ends, provided initially for attaching the pressure clamps used in the welding process. The locomotive used in making all of the moves was a Mallet type (2-6-6-0), weighing 528 000 lb., and having a weight on the drivers of 332 000 lb. and traction of 76 400 lb.

In the different moves, the rails were dragged at a speed of approximately 10 m.p.h., the first of the lengths being pulled completely through the tunnel to the west end of the proposed continuous section of the welded track. From this point, the individual moves were progressively shorter as the work continued through the tunnel to the east portal. In each successive move of two of the long lengths of rail, the sledding operation progressed until the forward ends reached a point approximately 1 100 ft. from the place where they were to be installed. Here, the rail anchors and spikes were left on the forward sled tie, the second sled tie was relieved of spikes and anchors and was chained to the rails of the running track, while all spikes and anchors were removed from the remaining sled ties.

With this arrangement, the locomotive pulled the welded lengths forward off the sled ties, dropping them into the center of the track as the move proceeded. The weld lugs at each joint skidded all of the ties together behind the second tie, massing them at this point, and then dragged across the tops of these ties as the rail was pulled forward. Little damage was done to these ties, which were used repeatedly in making the various moves, or to the crossties of the running track as the long lengths were dragged forward to the point of final installation.

In the method of sledding employed, a minimum of starts and stops were made by the locomotive, which naturally speeded up the work. Aside from the one stop required at the point where the rails were pulled from the sled ties, the only other stops involved were when the rail ends reached their final location where the yoke was uncoupled, and later, when the locomotive moved backward to a point where the bunched sled

ties could be picked up and loaded onto a flat car coupled ahead of the locomotive, for their removel from the tunnel. Throughout the entire work, an average of 5 700 lin. ft. of rail was taken into the tunnel each 10-hr. working period, each of which periods afforded only about 7 actual working hours because of interference by train operation. The shortest haul was approximately 1 000 ft., while the maximum move was about 6.5 miles.

Two of the 990-ft. welded lengths, supported on sled ties at intervals of about 40 ft., ready to be dragged into the tunnel.

Laying the rail.

The actual laying of the 990-ft. lengths was done by a special rail laying organization, and involved little variation from the ordinary methods of carrying out such work. The old rail was lined out of the track; the old single-shoulder tie plates were removed; all spike holes were plugged with treated plugs; plate-cut ties were hand adzed to provide new level plate seats; new double-shoulder tie plates were placed; and then the 990-ft. lengths of rail were lined over into place and gaged, spiked and anchored. At the same time, specially drilled angle bars were applied temporarily to the joints between the successive long lengths, employing the welding clamp web hole in each rail end, until the

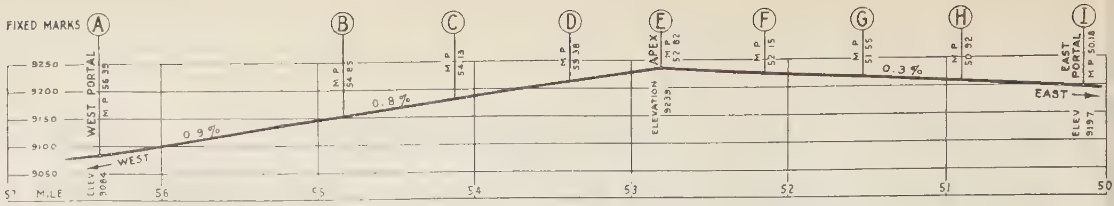
lengths could be welded together. The making of the closure welds was done by the thermit-pressure method, in a manner similar to that used in making the other welds, except that metal inserts were employed between the abutting rail heads.

Where some slight longitudinal adjustment of the 990-ft. rail lengths was necessary in laying them, to bring abutting ends into proper position for welding, this was done with little difficulty by the track forces, using lining bars given purchase against other bars passed through the welding clamp holes in the webs of the rails at a number of the 66-ft. weld locations. In the anchoring of the rail, 10 Fair anti-creepers were applied per 66-ft. length against expansion or creepage down grade, and 6 such anchors were applied to each 66-ft. length against movement up grade. Numerous permanent markers were installed in order that any longitudinal movement of the rails may be detected, but in view of the relatively constant temperature throughout the main body of the tunnel and the secure anchorage afforded by the anti-creepers and the double-shoulder tie plates, no difficulty with longitudinal movement is expected. A detailed record of the rail movements during June, July and August, 1938, is given in the accompanying table.

The joint welding on the rail racks was carried out by a force of 18 men, including 2 welders, while the relaying force, which did all of the work from the distribution of the new materials to the picking up of all released materials and the tamping of any swinging ties, consisted of 86 men. This latter force included 14 men assigned specifically to the handling of electric floodlights or strings of 75-watt incandescent lamps for illuminating the various laying operations.

As stated earlier in this article, in addition to the installation of continuously welded rails in the tunnel to help offset the effects of corrosion, the Denver and Salt Lake has been carrying out a wide range of experiments to develop means of minimizing the influences causing corrosion or electrolytic deterioration of the rail and fastenings within the tunnel. Its first experiments were with a large variety of anti-corrosion products or compounds, applied both under actual service conditions and in the well-equipped laboratory of the Denver and Rio Grande Western R. R. These tests demonstrated conclusively that none of the materials employed would allay entirely the sulphurous acid corrosion of the rail and fastenings, and that in certain cases, after varying periods of application, they actually caused accelerated corrosion. This latter condition was brought about as the result of the acid becoming housed between the plastic protective coating and the steel. The tests also demonstrated that certain metal coatings are of little effect.

As a result of these tests, and the inherent difficulty of maintaining any effective anti-corrosion compound between the rail base and the tie plates, further consideration of surface treatments has been abandoned. In its stead, the cathodic method of protection (electrolytic bath) is being experimented with extensively in an effort to minimize at least that part of the corrosion resulting from electrolytic action. This method offers protection only where current enters the metal, and its application to the rail would require that an electric current be passed through the rail; that a ground wire be run under each rail, as nearly parallel with it as possible; and that the rail base be surrounded by a conductor. There is a possibility that the damp cinders built up around the base of the rail will provide this conductor, but it is recognized that the periodic removal of the cinders will destroy this necessary element of the method. In any event, tests will be made to determine the protection offer-



DATE	(A)				(B)				(C)				(D)				(E)				(F)				(G)				(H)				(I)				(B) TEMPERATURE DEGREES	(G) TEMPERATURE DEGREES
	N-RAIL		S-RAIL		N-RAIL		S-RAIL		N-RAIL		S-RAIL		N-RAIL		S-RAIL		N-RAIL		S-RAIL		N-RAIL		S-RAIL		N-RAIL		S-RAIL		N-RAIL		S-RAIL		N-RAIL		S-RAIL			
	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W		
June 1	0	0	0	0	0	0	0	0																														
" 2	0	0	0	0	–	¼	–	¼																														
" 3	–	¼	–	¼	0	0	0	0																														
" 4	0	0	0	0	–	¼	–	¼																														
" 6	0	0	0	0	0	0	0	0																													+ 56°	+ 64°
" 8					0	0	0	0	0	0	–	½	¼	–	0	0	¼	–	0	0	0	0	0	0	0	0	0	0					0	0	0	0		+ 63°
" 9					0	0	–	¼	0	0	–	¾	0	0	0	0	0	0	–	½	–	¼	–	⅛	0	0	–	⅛									+ 62°	+ 55°
" 10	0	0	0	0	0	0	–	⅛	0	0	–	1	0	0	–	⅛	0	0	–	⅜	0	0	–	¼	–	¼	–	¼									+ 62°	+ 59°
" 11									⅛	–	–	½													–	¼	0	0										
" 14					–	⅛	–	¼	–	¾	–	¾	0	0	–	¼	–	¼	–	¾	0	0	0	¾	–	¼	0	0									+ 60°	+ 58°
" 16																																	0	0	–	½		
" 17	–	⅛	–	⅛	¼	–	–	¼	–	½	–	½	–	¼	0	0	¼	–	–	¾	–	¼	–	¾	–	¼	–	⅝	0	0	0	0	0	0	–	¼	+ 61°	+ 61°
" 18	–	¼	–	½	¼	–	–	½	⅝	–	–	¾	½	–	0	0	¾	–	0	0	0	0	–	1	–	¼	–	¾	–	½	0	0	0	0	–	¼	+ 60°	+ 62°
" 20	0	0	–	¼	⅜	–	–	¼	½	–	–	¾	¾	–	0	0	¾	–	–	½	⅜	–	–	1	–	¼	–	1	–	¼	0	0	0	0	0	0	+ 60°	+ 65°
" 21	–	⅛	–	¼	¼	–	–	⅜	¾	–	–	⅝	¾	–	0	0	15/16	–	–	⅜	½	–	–	¾	–	¼	–	¾	–	¼	0	0	0	0	0	0	+ 62°	+ 66°
" 22	–	¼	–	½	¼	–	–	⅜	¾	–	–	⅝	⅞	–	0	0	1⅛	–	–	¼	⅜	–	–	1	–	¼	–	1	–	¼	–	¼	–	⅛	–	¼	+ 66°	+ 65°
" 23	–	¼	–	½	¼	–	–	½	¾	–	–	¾	⅞	–	0	0	1⅛	–	–	¼	⅜	–	–	1⅛	–	¼	–	1	–	¼	–	⅜	0	0	–	¼	+ 60°	+ 62°
" 24	–	⅜	–	½	¼	–	–	¼	⅜	–	–	¾	1	–	–	⅛	1	–	–	⅜	¼	–	–	1⅛	–	¼	–	1⅛	–	¼	–	⅛	0	0	–	⅜	+ 62°	+ 61°
" 25	–	½	–	½	⅜	–	–	¼	⅞	–	–	¾	1½	–	–	⅛	1⅛	–	–	⅛					0	0		1	–	¼	0	0	0	0	–	½	+ 60°	+ 64°
" 26																																	0	0	–	½		
" 27	–	⅛	–	⅜	½	–	–	¼	¾	–	–	1	1	–	0	0	1⅛	–	–	½					–	⅜	–	1	–	½	–	¼	0	0	0	0	+ 58°	+ 65°
" 28	⅛	–	–	¼	⅜	–	–	⅜	¾	–	–	¾	1⅛	–	–	⅛	1	–	–	¾					–	⅜	–	1⅛	–	⅜	–	⅛	0	0	0	0	+ 62°	+ 66°
" 29	0	0	–	¼	⅜	–	–	⅜	15/16	–	–	⅞	1 3/16	–	0	0	1⅜	–	–	⅜					–	⅜	–	1 3/16	–	¼	–	0	0	0	–	¼	+ 58°	+ 66°
" 30	0	0	–	¼	⅜	–	–	⅜	¾	–	–	¾	1⅛	–	–	¼	1⅛	–	–	½					–	⅜	–	1					0	0	–	⅛	+ 60°	+ 64°
July 1																	1	–	–	½					–	⅜	–	1⅛					0	0	0	0	+ 64°	
" 2	0	0	–	⅜	¼	–	–	¼	⅞	–	–	⅞	1⅛	–	–	⅛	1⅛	–	–	⅝	15/16	–	–	1⅛	–	¼	–	1 3/16	–	⅛	0	0	–	¼	–	¼	+ 56°	+ 63°
" 5	½	–	–	3/16	½	–	–	¼	1	–	–	⅞	1¼	–	0	0	1⅜	–	–	⅜	1	–	–	1 3/16	–	¼	–	1 3/16	0	0	0	0	0	0	0	0	+ 59°	+ 66°
" 6	[illegible]	–	–	½	7/16	–	–	¼	1	–	–	15/16	1¼	–	–	¼	1¼	–	–	¼	1	–	–	1¼	–	⅜	–	1⅛	–	¼	–	⅛	–	⅛	–	¼	+ 56°	+ 64°
" 7	7/16	–	–	7/16	½	–	–	5/16	15/16	–	–	1⅛	1 3/16	–	0	0	1 5/16	–	–	½					–	¼	–	1 3/16	–	3/16	–	⅛	0	0	–	¼	+ 58°	+ 66°
" 8	3/16	–	–	⅛	¼	–	–	7/16	1⅛	–	–	⅞	1⅜	–	0	0	1¼	–	–	½					–	¼	–	1 3/16	–	3/16	–	⅛	–	⅛	–	⅛	+ 60°	+ 68°
" 9	¼	–	–	½	½	–	–	⅜	1⅛	–	–	1⅛	1 5/16	–	0	0	1 3/16	–	–	¾					–	¼	–	1¼	–	¼		⅛	0	0	–	½	+ 58°	+ 64°
" 11	⅜	–	–	¼	15/16	–	–	5/16	⅞	–	–	1⅛	1¼	–	–	⅛	1 5/16	–	–	⅝	1⅛	–	–	1¼	–	¼	–	1 3/16	–	⅛	0	0	0	0	–	¼	+ 56°	+ 70°
" 12	⅛	–	–	¼	¼	–	–	7/16	⅞	–	–	1⅛	1 5/16	–	–	⅛	1⅜	–	–	⅞	1	–	–	1½	–	¼	–	1¼	–	¼	–	¼	0	0	–	¼	+ 62°	+ 60°
" 13	⅛	–	–	5/16	5/16	–	–	⅜	1	–	–	1⅛	1 3/16	–	0	0	1⅜	–	–	7/16	1	–	–	1⅜	–	⅛	–	1¼	–	⅛	0	0	0	0	–	¼	+ 62°	+ 66°
" 14	⅛	–	–	¼	⅜	–	–	⅜	1 3/16	–	–	1⅛	1⅛	–	–	⅛	1⅛	–	–	½	1	–	–	1⅛	–	¼	–	1 3/16	0	0	0	0	0	0	–	¼	+ 58°	+ 64°
" 15	⅛	–	–	¼	½	–	–	½	1	–	–	1	1¼	–	0	0	1⅜	–	–	⅜	1⅛	–	–	1¼	–	¼	–	1 3/16	–	⅛	0	0	0	0	–	¼	+ 60°	+ 64°
" 16	[illegible]	–	–	½	1¼	–	–	7/16	¾	–	–	1	1 3/16	–	–	⅛	1½	–	–	1 7/16	1⅛	–	–	1½	–	¼	–	1⅛	–	⅛	–	¼	0	0	–	¼	+ 58°	+ 66°
" 18	3/16	–	–	¼	15/16	–	–	7/16	1	–	–	1⅛	1 5/16	–	–	⅛	1¼	–	–	1⅛	1⅛	–	–	1½	–	¼	–	1 3/16	–	⅛	–	⅛	–	⅛	–	⅜	+ 64°	+ 64°
" 19	¼	–	–	¼	1	–	–	½	1	–	–	1	1¼	–	–	⅛	1½	–	–	¾	1⅛	–	–	1½	–	¼	–	1¼	–	¼	–	¼	–	⅛	–	¼	+ 62°	+ 64°
" 20	⅜	–	–	½	⅜	–	–	⅜	1⅛	–	–	⅞	1 7/16	–	–	⅞	1⅜	–	–	⅞					3/16	–	–	¾	⅛	–	0	0	–	⅛	0	0	+ 58°	+ 66°
" 21	5/16	–	–	¼	½	–	–	¼	15/16	–	–	⅞	1 5/16	–	–	⅜	1½	–	–	15/16					⅜	–	–	¾	–	3/16	–	⅛	–	1/16	–	¼	+ 58°	+ 64°
" 22	7/16	–	–	½	½	–	–	⅜	15/16	–	–	1	1⅜	–	–	¼	1½	–	–	⅞					¼	–	–	⅞	0	0	0	0	0	0	–	¼	+ 60°	+ 64°
" 23	½	–	–	½	½	–	–	½	1	–	–	15/16	1¼	–	–	⅜	1 7/16	–	–	1					⅜	–	–	½	0	0	0	0	–	⅛	–	¼	+ 60°	+ 62°
" 25	½	–	–	⅜	½	–	–	⅜	15/16	–	–	1	1¼	–	–	¼	1½	–	–	⅞					3/16	–	–	¾	0	0	–	⅛	–	⅛	–	⅜	+ 62°	+ 64°
" 26	0	0	–	5/16	⅞	–	–	⅞	1 3/16	–	–	1 3/16	1 7/16	–	–	⅞	1⅜	–	–	15/16					¼	–	–	⅜	3/16	–	–	⅛	–	⅛	–	⅜	+ 58°	+ 66°
" 27	¼	–	–	⅛	¼	–	–	7/16	15/16	–	–	1 7/16	1 5/16	–	–	½	1 3/16	–	–	1⅛					¼	–	–	¾	¾	–	–	⅛	⅛	–	–	⅛	+ 62°	+ 64°
" 28	¼	–	–	¼	¼	–	–	¾	¾	–	–	1⅛	1¼	–	–	¾	1¾	–	–	1½	–	½	–	1½	–	¼	–	1	¼	–	¼	–	0	0	0	0	+ 62°	+ 63°
" 29	½	–	–	⅛	¼	–	–	¾	½	–	–	1⅛	1¼	–	–	¾	1¾	–	–	1½	–	½	–	1½	–	¼	–	1	¼	–	¼	–	0	0	0	0	+ 62°	+ 64°
" 30	¼	–	–	¼	¼	–	–	¾	⅝	–	–	1⅛	1¼	–	–	¾	1¾	–	–	1½	–	½	–	1½	–	¼	–	1	¼	–	¼	–	0	0	0	0	+ 62°	+ 62°
August 1	–	¼	–	½	¼	–	–	¾	¾	–	–	1⅛	1¼	–	–	¾	1¼	–	–	1¼	–	½	–	1¼	½	–	–	½	¼	–	¼	–	0	0	0	0	+ 62°	+ 60°
" 2	–	½	–	¾	¼	–	0	0	1	–	–	1¼	1	–	–	½	1¼	–	–	1	–	¼	–	1	½	–	–	¾	0	0	0	0	¼	–	0	0	+ 64°	+ 64°
" 3	–	⅜	–	¼	0	0	–	½	½	–	–	1	1	–	–	½	1½	–	–	1	1	–	0	0	¾	–	–	1	0	0	0	0	¼	–	0	0	+ 64°	+ 62°
" 4	–	¼	–	1	0	0	–	½	¾	–	–	1	1	–	–	1	1½	–	–	¾	1	–	0	0	½	–	–	1	¼	–	¼	–	0	0	0	0	+ 62°	+ 62°
" 5	–	½	–	1	½	–	0	0	1	–	–	1¼	1½	–	–	¾	1¾	–	–	1¼	0	0	0	0	½	–	–	½	¼	–	¼	–	0	0	0	0	+ 62°	+ 66°
" 6	–	½	–	¾	¼	–	–	¾	1	–	–	1¼	1¼	–	–	¾	1½	–	–	1	–	½	–	1½	½	–	–	½	0	0	0	0	0	0	0	0	+ 62°	+ 64°
" 8	–	¼	–	¾	0	0	–	½	1	–	–	1	1	–	–	1	1½	–	–	1	0	0	–	1	0	0	0	0	¼	–	0	0	0	0	0	0	+ 64°	+ 60°
" 9	–	½	–	½	0	0	–	¼	¾	–	–	1¼	1	–	–	1	1½	–	–	1	0	0	–	1	0	0	0	0	¼	–	0	0	0	0	0	0	+ 64°	+ 60°
" 10	–	¼	–	¼	0	0	–	¾	1	–	–	1½	1½	–	–	1	1½	–	–	1	–	1	–	1	¼	–	–	½	¼	–	0	0	0	0	0	0	+ 64°	+ 60°
" 11	–	¼	–	¾	0	0	–	½	1¼	–	–	1½	1¾	–	–	1	1½	–	–	1	–	¾	–	1½	½	–	–	¾	0	0	–	½	¼	–	0	0	+ 64°	+ 64°
" 12	–	¼	–	½	0	0	–	½	1¼	–	–	1¼	1¼	–	–	1	1½	–	–	1	–	1	–	1¾	½	–	–	1	0	0	–	¼	0	0	0	0	+ 64°	+ 64°
" 13	–	¼	–	½	0	0	–	½	1¼	–	–	1½	1½	–	–	1	1½	–	–	1	–	1	–	2	½	–	–	1	0	0	–	½	0	0	0	0	+ 64°	+ 62°
" 15	0	0	–	¼	½	–	–	¾	1	–	–	1¼	¾	–	–	½	1¾	–	–	2	½	–	–	1¼	½	–	–	¼	0	0	–	¼	0	0	0	0	+ 65°	+ 64°
" 16	0	0	–	¼	0	0	–	¾	1	–	–	1¼	¾	–	–	½	2	–	–	2¼	½	–	–	1¼	¾	–	–	¼	0	0	–	¼	0	0	0	0	+ 66°	+ 64°
" 17	0	0	0	0	0	0	–	¾	1	–	–	1¼	1	–	–	½	2¼	–	–	1¾	¾	–	–	1½	¾	–	–	¼	0	0	–	¼	0	0	0	0	+ 66°	+ 62°
" 18	0	0	0	0	¼	–	–	¾	1	–	–	1¼	1	–	–	¾	1¾	–	–	1½	1	–	–	2	1	–	–	¼	0	0	–	½	0	0	0	0	+ 64°	+ 64°
" 19	0	0	0	0	½	–	–	½	1	–	–	1½	1¼	–	–	¾	2	–	–	1½	1	–	–	2	½	–	–	¾	0	0	–	½	0	0	0	0	+ 64°	+ 62°
" 20	–	¼	–	½	½	–	–	½	1¼	–	–	1½	1½	–	–	½	1½	–	–	2	1	–	–	1¾	½	–	–	¾	¼	–	–	½	0	0	0	0	+ 66°	+ 66°
" 22	0	0	–	½	½	–	–	¼	1¼	–	–	1½	¾	–	–	½	1½	–	–	2¼	1½	–	–	1½	1	–	–	¾	¼	–	–	½	0	0	0	0	+ 64°	+ 66°
" 23	0	0	–	½	0	0	–	¾	1	–	–	1½	¾	–	–	½	2	–	–	1½	¾	–	–	1¼	½	–	–	1	0	0	–	¼	0	0	0	0	+ 66°	+ 62°
" 24	–	¼	0	0	0	0	–	¾	1	–	–	1½	1	–	–	¾	2¼	–	–	1½	1	–	–	1½	½	–	–	1	¼	–	0	0	0	0	0	0	+ 64°	+ 62°
" 25	0	0	0	0	0	0	–	¾	1	–	–	1¼	1½	–	–	¼	2	–	–	1¾	½	–	–	1¾	¾	–	–	1	0	0	–	¼	0	0	0	0	+ 66°	+ 62°
" 26	0	0	0	0	0	0	–	½	1	–	–	1¼	1½	–	–	¼	1¾	–	–	2	½	–	–	1	1	–	–	1	¼	–	–	½	0	0	0	0	+ 66°	+ 64°
" 27	0	0	–	¼	¼	–	–	½	1	–	–	1½	1½	–	–	¼	1¼	–	–	2¼	1	–	–	2	½	–	–	1	0	0	–	¼	0	0	0	0	+ 64°	+ 64°
" 29	0	0	0	0	¼	–	–	½	1	–	–	1½	1¼	–	–	¾	1½	–	–	2	1	–	–	1¾	¾	–	–	¼	¼	–	–	½	0	0	0	0	+ 64°	+ 64°
" 30	0	0	0	0	½	–	–	¾	1¼	–	–	1½	¾	–	–	½	2	–	–	1½	¾	–	–	1	1	–	–	½	¼	–	–	½	0	0	0	0	+ 64°	+ 62°
" 31	0	0	–	½	0	0	–	¾	1	–	–	1¼	1½	–	–	½	2	–	–	1½	1	–	–	2	1	–	–	½	0	0	–	¼	0	0	0	0		+ 62°

Measurements of movement (inches) of 6.45 miles of continuous welded rail in Moffat tunnel, three months period — June, July, August, 1938.

ed by the method where the rail base is surrounded by cinders. Tests of the cathodic method already conducted within the tunnel with small pieces of angle bar and strap iron have demonstrated that corrosion may be retarded as much as 30 per cent, and indicate that even greater protection may be possible in the case of the track rail.

Neutralize acid.

Since the major cause of corrosion within the tunnel is the sulphurous acid generated as the result of the combustion of locomotive coal, it is felt that if this acid can be neutralized, corrosion will be reduced materially. Working on this theory, consideration is being given to impregnating the locomotive gases with a neutralizing agent such as lime. We now believe that the most feasible method of doing this would be to equip each engine operating through the tunnel with a small feeder filled with lime of the proper strength, which can be turned on about a half mile before the tunnel is reached, feeding the lime gradually into the stack until the tunnel is passed. Such an arrangement, we believe, will result in neutralizing the corrosive elements in the stack gases and will thus afford protection to the rail and fastenings.

Another possible aid being considered to minimize corrosion is the use of a continuous blow-off from locomotive boilers, directed against the rails. All engines carry about 15 grains of alkalinity per gallon in their boiler water. It is felt that a small stream of this water played on the rails will, over a long period, deposit a sufficient amount of alkaline material over their surface to neutralize any acid coming in contact with it.

Consideration is also being given to the installation of a small turbine-driven electric generator on the side of each locomotive operated through the tunnel, the current generated to be stepped up through a transformer and a synchronised rotary gap, and then discharged through electrodes suspended in the locomotive stack, in the presence of the stack cinders as exhausted. The idea behind this scheme is that under the action of the electric charge, the cinders will be precipitated on the inside of the stack or in adjacent containers provided until the engine has passed through the tunnel, after which they will be expelled into the air by the velocity of the smoke and gases in the stack.

The efforts to overcome the corrosion problem within the Moffat tunnel have been advocated and planned by the author, assisted in all testing work by Ray McBrian and associates, testing engineers for the Denver and Rio Grande Western R.R. The rail welding described was carried out by section forces under the supervision of representatives of the Metal and Thermit Corporation, while the installation of the continuous rail was made by company forces under the direction of G. S. Turner, engineer maintenance of way of the Denver and Salt Lake Railway.

[625. 251]

The friction of brake shoes at high speed and high pressure (*).

Tests at University of Illinois Experiment Station indicate the practicable limits of the rate of work performance for both shoe and wheel protection.

(Railway Age.)

The tests described in this bulletin were undertaken at the University of Illinois Engineering Experiment Station because of the recent revival of interest in brake-shoe friction. A general increase in the speed of all trains, climaxed by the development of the high-speed streamline trains, has shown the necessity of supplementing existing test data in order to be able to predict their stopping distance. The chief purpose of the tests was to determine the values of the coefficient of friction of railway brake shoes under conditions similar to those which prevail on the road in stopping trains traveling at high speed by means of high pressures on the shoe of the car wheel.

During the investigation 432 stops were made. The tests were run at shoe pressures from 4 500 to 20 000 lb. Under each of these pressures stops were made from initial speeds of 60, 80 and 100 miles an hour. The results are in accord with those of previous experiments in which the maximum shoe pressure was about 15 000 lb. and the maximum speed about 65 miles an hour. Beyond these limits there is a definite change in the trend of the results. This variation is caused by the drastic change in the behaviour of the shoe material which occurs when shoe pressures above 15 000 lb. are combined with speeds above 60 m. p. h.

During the tests 21 brake shoes were used. They were all unflanged Diamond S reinforced-steel-back shoes and were made by the American Brake Shoe and Foundry Company. With five exceptions, all of the shoes had chilled ends. All tests were made upon a multiple-wear rolled-steel wheel 33 in. in diameter for use on 6-in. by 11-in. axles. It was made during July, 1930, and was chosen by a representative of the university from the wheel stock of a western railroad. The tread is of the double-taper contour which was maintained during all the tests. Its weight, ready for test, was 773 lb.

All tests were so-called stop tests in which the test conditions simulate those which prevail in service when the brakes of a train are applied to bring it to a stop. The brake-shoe pressure remains constant throughout the stop, but the tangential pull and the coefficient of friction vary somewhat during the period of the stop. The coefficient of friction value reported for the stop is its average value during this period. Five

(*) This article is a condensed abstract of *Bulletin* No. 301 *of the University of Illinois Experiment Station* entitled « The friction of railway brake shoes at high speed and high pressure », by Herman J. SCHRADER, assistant professor of mechanical engineering. Price, 60 cents. The article is largely confined to a statement of the results of the tests and conclusions drawn therefrom, with little attention to the details of methods or to the wealth of test data on which the statement of results is based.

stops under the same pressure and initial speed constitute a test and, in general, the average value of the coefficient of friction for the five stops is reported.

The data recorded during each stop provide means for determining, in addition to the average coefficient of friction, the coefficient of friction, the elapsed time and the distance run for various intervals from the beginning to the end of the stop. During some of the tests the temperature of the brake shoe and of the wheel tread were measured by means of inserted thermocouples. In all tests all calculations in determining the result of the coefficient of friction are based on the kinetic energy existing in the revolving unit at the time the brake shoe is applied.

Coefficient of friction.

For each of the three initial speeds the coefficient-of-friction values are plotted in fig. 1, for all the various shoe pressures.

As in previous experiments, the coefficient of friction decreases as the initial speed is increased. At speeds of 60 and 80 miles an hour, there are no exceptions to this decrease with speed throughout the entire pressure range. At the speed of 100 miles an hour, however, there is a recovery of the coefficient at shoe pressures above 14 000 lb., such that at 15 000 and 16 000 lb. the coefficient at 100 miles an hour is greater than at 80 miles an hour. At shoe pressures of 18 000 and 20 000 lb., the coefficient at 100 miles an hour is not only greater than at 80 miles an hour, but it is also greater than the coefficient at 60 miles an hour.

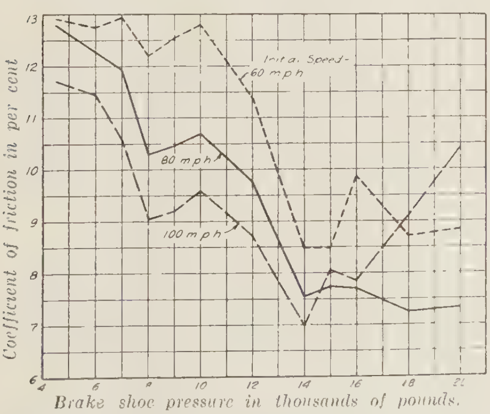


Fig. 1. — Relation between coefficient of friction and brake-shoe pressure, for all tests.

Previous experiments have shown a general decrease in coefficient of friction as the shoe pressures are increased. In general, these tests show a similar decrease except at the higher pressures used. The actual variations of coefficient with pressure are shown in fig. 1. With one exception (at 7 000 lb. and 60 miles an hour), the coefficient decreases at all three speeds until the shoe pressure reaches 8 000 lb. From this point, however, it rises again until the shoe pressure becomes 10 000 lb. This temporary rise in the coefficient may, perhaps, be due to the better seating of the shoe on the wheel under pressures of 7 000 and 10 000 lb., or to inherent frictional qualities of the shoes Nos. 8 and 9. Beginning at a pressure of 10 000 lb., there is, under all three speeds, a definite and rapid decrease in the coefficient of friction until the shoe pressure reaches 14 000 lb. From this point, at speeds of 60 and 80 miles an hour, with one exception (16 000 lb. and 60 miles an hour), the coefficient remains practically constant. At 100 miles an hour, however, the coefficient increases rapidly for pressures above 14 000 lb. (which gives a coefficient of friction of only 6.95 per cent), becoming 8.04, 7.84, 9.10 and 10.41 per cent at pressures of 15 000 lb., 16 000 lb., 18 000 lb., and 20 000 lb., respectively.

The reason for this recovery in coefficient of friction at shoe pressures in excess of 14 000 lb. probably lies in the fact that under these higher combinations of speed and pressure the rate of heat generation is so high that the shoe

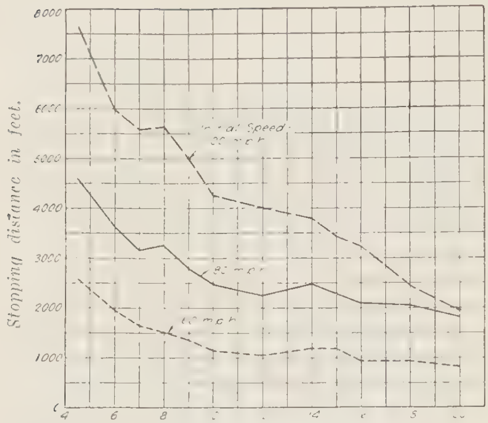


Fig 2. — Relation between stopping distance and brake-shoe pressure, for all tests.

material begins to soften at the surface of contact. Such a surface softening of the shoe would result in more intimate contact between shoe and wheel, and in more rapid tearing away of the shoe material; and both of these changes would account for the increase in the coefficient of friction. This view is well supported by the recorded rise in shoe temperature under these severe conditions, by the fact that a continuous stream of particles of molten metal issues from beneath the shoe during most of its period of application, and by the very marked increase in the shoe wear which occurs at these combinations of high speed and high pressure.

Stopping distance.

Stopping distance, since it combines the effects of both coefficient of friction and shoe pressure, provides a means for more direct comparisons of the effectiveness of various combinations of speed and pressure than is provided by the coefficient alone. The average values of stopping distance are plotted for all pressures and each of the three speeds in fig. 2. At each of the three test speeds the stopping distance decreases fairly regularly as the shoe pressure is increased. At both 60 and 80 miles an hour the rate of decrease diminishes, however, at the higher pressures, so that at neither of these speeds was very much gained by increasing the pressure above 12 000 lb. At speeds of 60 miles an hour the increase in pressure from 12 000 lb. to 20 000 lb. produced a decrease in stopping distance of only 224 ft. At speeds of 80 miles an hour the corresponding change in pressure produced a decrease in distance of 437 ft. During the tests from an initial speed of 100 miles an hour, however, an important decrease in distance was attained by increasing the pressure from 12 000 to 20 000 lb. At the former pressure the average stopping distance was 4 006 ft., whereas at the higher pressure the distance was only 1 930 ft. — a decrease of 2 076 ft. Unfortunately, however, at both 80 and 100 miles an hour, pressures much in excess of 12 000 lb. produce an excessive shoe wear; and apparently at these two speeds an increase in shoe pressure above about 14 000 lb. will prove, on this account, to be impracticable. The tests at high speed and high pressure also caused serious damage to the wheel tread.

Brake-shoe wear.

The weight lost per hundred million foot-pounds of work performed is the unit usually employed to define shoe wear. Fig. 3 shows the wear in terms of this unit, plotted with respect to shoe pressure for each of the three test speeds.

During the tests at 60 miles an hour the shoe wear was of moderate and tolerable amount throughout the entire pressure range, although there was a fourfold increase in the wear between pressures of 4 500 lb. and 20 000 lb.

Considering the results for speeds of 80 miles an hour, it is apparent that for

pressures from 4 500 lb. to 12 000 lb. the shoe wear is very moderate. With pressures higher than 12 000 lb. the wear increases, until at 18 000 lb. the wear is ten times that at 4 500 lb. Although this increase in the wear is of a considerable magnitude, it is not intolerable, and it is likely that the higher pressures can be used to advantage in train service where the maximum speed is about 80 miles an hour.

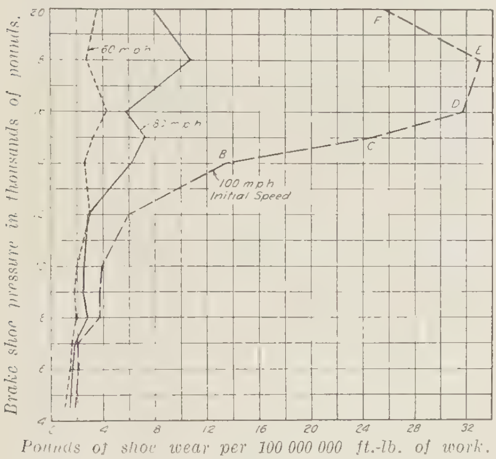


Fig. 3. — Relation between brake-shoe pressure and brake-shoe wear, for all tests.

During tests at 100 miles an hour a radical change in the rate of shoe wear begins at point *A*, corresponding to a pressure of 12 000 lb. At points *A*, *B*, *C*, *D*, *E* and *F* the average wear per stop is, respectively, 0.25 lb., 0.56 lb., 0.99 lb., 1.26 lb., 1.30 lb., and 1.02 lb. Obviously, at point *A* some fundamental change in the behavior of the shoe material begins. The test records show that at pressures beyond this point a marked rise in shoe temperature occurs, and that there is a softening of the shoe material as evidenced by the continuous ejection of molten particles from the shoe surface. Furthermore, the shoes are not only rapidly worn away under these severe test conditions, but even a new shoe after one or two applications may be so badly cracked as to render it unfit for further service. Evidently the point *A* marks the beginning of conditions which cause a breakdown in the shoe material, which at pressures beyond that prevailing at this point become so serious as probably to render the use of higher pressures impracticable. The shoes of pattern C-40 and C-51, when new weigh respectively 20 and 25 lb., and when worn to the thickness at which they would usually be discarded they weigh about 11 lb.; there is available, therefore, about 9 lb. and 14 lb. of wearable metal, respectively, on the two shoes. Consequently, at the rate of wear prevailing during stops from 100 miles per hour and at pressures above 14 000 lb., the thin shoe would have to be rejected from service after from six to nine stops, and the thick shoe after from ten to fourteen stops. Disregarding any damage done to the wheel by the combinations of high speed and high pressure, the shoe wear alone may render these high pressures impracticable.

Evidently there are, at high speeds, limits to the pressures which may practically be used in train brakes if this general breakdown in shoe material is to be avoided. These limits are imposed by the overheating of the shoe, and they cannot, therefore, be defined by setting a limit to the number of foot-pounds of work to be performed by the shoe without regard to the time within which the work has to be performed. The limits must be defined in terms of the time-rate of work performance, instead of in terms of its mere magnitude. The relations between the foot-pounds of work performed and dissipated per second and the pounds of shoe wear per 100 million ft.-lb. of work done are plotted in fig. 4, for all combinations of pressure and speed. On this graph the points lettered *A*, *B*, *C*, *D*, *E*, and *F* correspond to the same combinations of speed and pressure as the points so lettered on fig. 3.

Since the difficulties arising from the change in behavior of the shoe begin to be acute under the conditions prevailing at points *B* and *C*, the limiting rates of work performance ought not to be greater than the rates which prevailed at those points, namely 78 000 and 98 500 ft.-lb. per second. The suggestion is offered that the limiting rate of work performance ought to be set at about 90 000 ft.-lb. per second. This limit is shown on fig. 4 by the heavy horizontal line. If this suggestion is accepted then the test results are to be interpreted as meaning that, if excessive wear and deterioration of brake shoes are to be avoided, no brake shoe of the types tested should be subjected to braking conditions which will require it to perform and dissipate more than 90 000 ft.-lb. of work per second.

The combination of high speed and high pressure causes a softening of the shoe surface, as evidenced by the continuous ejection of molten metal particles. The molten metal was not only scattered over the laboratory but a large amount of it was welded to the surface of the wheel. If this material is not removed from the tread, the building up of the spots is cumulative since during the next stop the shoe, bearing only on these spots, will deposit an additional layer of metal. In train service, this building up of shoe material on the wheel tread may be a cause of hard riding cars. In some cases this welded material is hard enough to make indentations in the rails.

In general the shoe material was not welded to the wheel surface until the pressure exceeded 16 000 lb. in the 60 miles-an-hour stops, and 12 000 and 10 000 lb. respectively, in the 80 and 100 miles-an-hour stops.

Since this difficulty occurred at combinations of speeds and pressures which required the shoe to perform and dissipate work at a rate of 70 000 ft.-lb. (or more) per second, it might be desirable, in some classes of service, to limit the rate of work performance to about 70 000 ft.-lb. per second. This limit is shown in fig. 4 by the heavy broken line.

All the cracks which developed in the wheels during the investigation occurred during the cooling of the wheel, and most of them occurred after the temperature had dropped to about room temperature. The formation of the crack was accompanied by a loud ringing sound similar to the sound caused by a sharp blow with a light hammer on the rim of the wheel. The cracks, as they first appeared on the tread, were about full length and only a few became longer on additional tests. None of the cracks extended into the throat or flange, or to the outside of the wheel rim.

In determining the maximum rate of work which can be performed on a

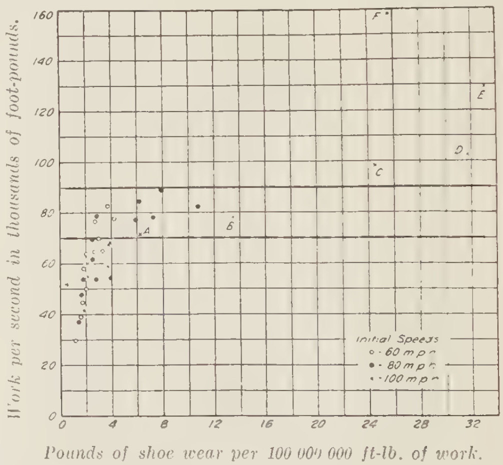


Fig. 4. — Relation between work per second and brake-shoe wear per 100 million foot-pounds of work, for all tests.

wheel without causing cracks on the tread, it is necessary to investigate a number of stops preceding the test during which the crack was formed. For example, the first crack appeared after Test No. 3 459, in which the average rate

of work, for the five stops, was only 68 411 ft.-lb. per second; however, during the two preceding tests the work-rate was about 125 000 ft.-lb. per second. Cracks Nos. 2 and 7 to 12, inclusive, were also formed during tests in which the work rate was relatively low, but immediately preceding the tests in which these cracks were formed the wheel had been subjected to stops in which the work-rate was very high. A study of the data indicates that cracks may or may not be formed by stops made at such combinations of speed and pressure as require the shoe to do work on the wheel at a rate of 125 000 ft.-lb. per second, but when this work-rate is exceeded cracks will almost certainly be formed.

The characteristic failure of all the shoes is cracked and broken ends. In a few cases this did not occur until the shoe was worn to about the allowable minimum thickness; very many shoes were rejected, however, on account of the ends failing, long before they reached this minimum thickness. Combinations of speed and pressure which gave low shoe wear did not crack or break the ends until the shoe was near the allowable minimum thickness. In all tests where the work-rate was over 90 000 ft.-lb. per second this failure occurred, and in some cases the ends gave way after only two or three stops.

Relative merits of shoes.

Four types of shoes were used in the tests. The tests to determine their relative merits were all made with pressures of 18 000 lb. and 20 000 lb., and speeds of 60, 80, and 100 miles an hour. In these tests two new shoes of each type were used. They are grouped as follows:

(a) Shoes Nos. 50 and 51 of pattern C-40, with chilled ends.

(b) Shoes Nos. 70 and 71 of pattern C-40, with plain ends.

(c) Shoes Nos. 100 and 101 of pattern C-51, with chilled ends.

(d) Shoes Nos. 120 and 121 of pattern C-51, with plain ends.

All were « Diamond S » reinforced steel-back shoes. The shoes of pattern number C-40 were 1 1/2 in. thick and weighed 20 lb. each when new, while those of pattern number C-51 were 2 in. thick and weighed 25 lb.

Considering the light and the heavy shoes, it is found that the coefficient of friction and the shoe wear is lower for the heavy shoes than for the light shoes; and that the stopping distance is greater for the heavy shoes than for the light ones. The main advantage of the heavy shoes is that in them an increase of 55 per cent of wearable metal is attained by an increase of only 25 per cent in weight. Except under conditions where the minimum stopping distance is of paramount importance, this fact may be regarded as offsetting the small deficiency in coefficient of friction of the heavier shoes.

Considering the plain and the chilled-end shoes, the co-efficient of friction, the stopping distance and the shoe wear are practically the same for these two types of shoes. The tendency for the ends of the shoes to crack and break was more pronounced on the chilled than on the plain shoes.

All four types of shoes wore away unevenly under the tests at high speeds and high pressures, and on some shoes the difference in thickness at the end was as much as 1/2 in. after the tests. In this respect the chilled-end shoes were slightly superior.

Conclusions.

The following conclusions seem warranted by the test results. They are applicable only to the types of shoes and the kind of wheel tested.

(1) If excessive wear and deterioration of brake shoes are to be avoided, no

cast-iron brake shoe should be subjected to braking conditions which will require it to perform and dissipate more than 90 000 ft.-lb. of work per second.

(2) The building up of the welded brake shoe material on the wheel tread may be avoided by limiting the braking conditions to combinations of pressure and speed such that the work-rate performance of the shoe is kept below 70 000 ft.-lb. per second.

(3) Shoe pressures of 20 000 lb. combined with high speeds, cracked the wheel tread at a very rapid rate, and the rate of performing work on the wheel should be kept below 125 000 ft.-lb. per second in order to avoid this type of failure.

(4) Under the conditions of shoe pressure and speed prevailing in these tests the heavy shoes of pattern C-51 are more economical than those of the lighter pattern C-40, and are preferable, unless the service conditions are such as to make minimum stopping distance of paramount importance.

(5) The chilled-end shoes were not superior to the plain-end shoes when tested at high speeds and high pressures.

[There are four appendices to the report in which the data bearing on variation of the coefficient of friction during the stopping period, variation of coefficient of friction with shoe thickness, relation between shoe bearing area and coefficient of friction, and the temperatures of wheel and shoe are presented and discussed. With respect to the first of these subjects the report concludes that, with shoe pressures below 16 000 lb., there is definite increase in the coefficient of friction beginning at a point where the speed has decreased to about 35 miles an hour and continuing to the end of the stop. At pressures above 16 000 lb. the coefficient is fairly uniform during the entire stopping period with the exception that during stops from an initial speed of 100 miles an hour the coefficient is high at the beginning and again high when the speed has decreased to about 60 miles an hour. With respect to the temperature of wheel and shoe, the conclusion is that some accurate method of measuring the surface temperature of a revolving wheel must be developed before any reliable conclusions can be drawn as to the relation of the surface temperature of the car wheel and car-wheel failures. The temperature at a point 5/16 in. below the surface is no indication of the surface temperature. A minimum of about 10 thermocouples would probably be required to give a reliable average temperature of the surface of the shoe. — *Editor, Railway Age*].

[62 (01 (.73) & 621. 134.1 (.73)]

Locomotive axle testing (*).

Results of fatigue tests on 11 1/2-in. unrolled and rolled axles.

(Railway Age.)

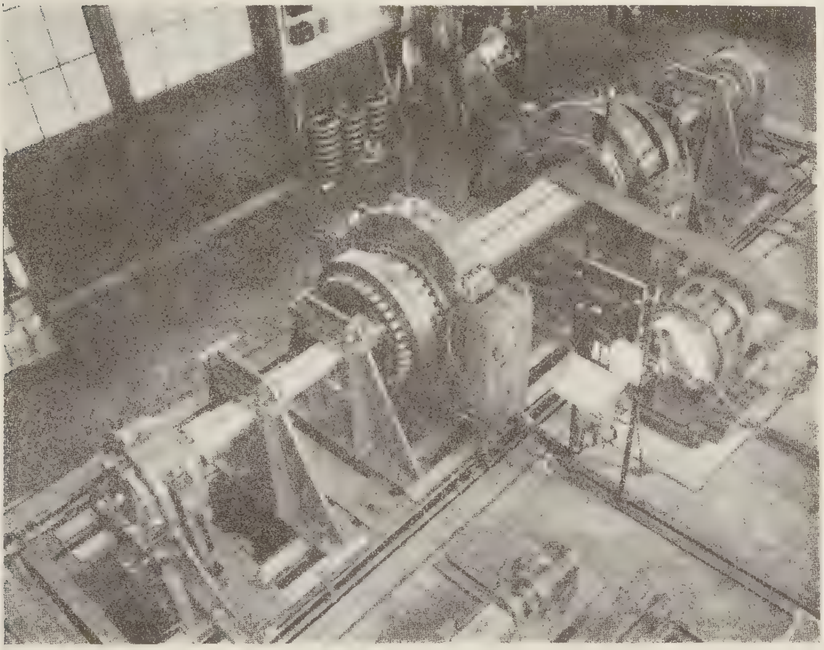


Fig. 1. — Timken testing machine for locomotive driving axles.

In view of the importance of fatigue cracks which develop in the wheel fit of axles in service, the Timken Roller Bearing Company initiated over a year ago a program of laboratory fatigue tests on outside-bearing electric-locomotive axles 11 1/2 in. in diameter at the wheel seat. The machine used in making these tests is designed so that two axles may be tested simultaneously as cantilever beams at the same or different bending stresses, one test axle-and-wheel assembly being located at each end of the machine as shown in figure 1. Constant vertical spring load is applied at the journal end of the axle opposite the axle end on which the wheel is mounted. The entire axle-and-wheel assembly is bolted to a rotating flange by means of 34 bolts at the rim of the wheel. The journal end of the axle protruding beyond the pressed-on wheel projects into the test-machine spindle which is hollow bored; there is no contact between the spindle and the axle-and-wheel assembly except at the bolted

(*) Abstracted from the paper « Locomotive Axle Testing », by T. V. Buckwalter, vice-president, O. J. Horger, research engineer, and W. C. Sanders, general manager railway division, Timken Roller Bearing Company. The paper was published in the May, 1938, issue of the *A. S. M. E. Transactions* and presented at the semi-annual meeting of the American Society of Mechanical Engineers at St. Louis, Mo., June 21, 1938.

rim of the wheel. A 100-H.P. variable-speed motor drives the machine through an eight-strand V-belt connected to the central drive shaft located between the two rotating flanges to which the axle-and-wheel assemblies are bolted.

wheel, except that the length of the spokes has been shortened; however, the sections of the hub, rim, spokes and shrunk-on tire are the same as used in service.

All the axles used for the tests were

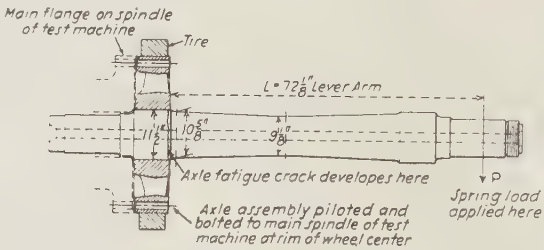


Fig. 2. — Details of axle-and-wheel assembly tested in the fatigue machine.

The accelerated test made with this machine produces axle fatigue fractures which have exceptionally close similarity to axle failures developed in service in that : — *(a)* the location and type of fatigue fractures in the wheel seat near the inside hub face in test axles are comparable with results in service; *(b)* initial development of a fatigue crack in test axles is produced at very low axle bending stress, but does not have appreciable propagation unless occasional high stresses are produced; a similar condition is found in service with ordinary speed equipment when magnetic examination is made of used axles before returning for new wheels; and *(c)* axles stresses at which the incipient fatigue cracks mentioned in *(b)* propagate to appreciable depth and then to complete failure of the test axle compare favorably with service experience with higher-speed equipment where higher occasional stresses would be experienced.

Description of 11 $^1/_2$-in. axles tested.

Figure 2 is a line drawing of the axle-and-wheel assembly tested, which has dimensions identical with those of axles used in service. This is also true of the

obtained from the same heat, and all axle forgings were given a normalizing and tempering treatment to produce the actual measured physical properties given in Table I, which also includes the chemical analysis. A 2-in. diameter hole was drilled through the center of all the axles. All axles assemblies were furnished by the Pennsylvania as shown in figure 2 completely machined, assembled and ready for test.

TABLE I. — **Chemical analysis and physical properties of axles tested.**

Chemical analysis :	
Carbon, per cent	0.24
Nickel, per cent	3.10
Sulphur, per cent	0.02
Phosphorous, per cent	0.03
Physical properties :	
Yield point, lb. per sq. in.	60 950-69 000
Ultimate strength, lb. per sq. in.	91 000-94 900
Elongation in 2 in., per cent	25.0-30.0
Reduction of area, per cent	67.5-70.6
Brinell hardness	192
Fatigue strength, 1/4-in. diameter rotating beam, lb. per sq. in.	55 300

The cast wheel centers used were of A. A. R. grade C steel and were pressed on the axles in accordance with standard railroad practice. The mounting

tonnages and diameter fits are given in Table II. A steel tire of 3 3/4-in. by 6-in. section was shrunk over each cast-steel wheel center after the center had been mounted on the axle as a means of nearly simulating the service assembly. The tire fit was 1/64 in. per ft. of wheel-center diameter.

Two uncompleted series of tests are reported in this paper, one series being on rolled axles while the other is on unrolled axles. The so-called rolled axles were surface-rolled (burnished) over the entire wheel fit portion before the wheel center was mounted on the axle for the purpose of investigating what increase in strength would result. In the rolling process the axle was rotated on lathe centers at 25 to 50 r.p.m. while the rollers were fed along the axle by the lathe carriage at the equivalent rate of about 28 threads per inch. The rolling device consists of three rollers spaced 120 deg. apart and the pressure used was 25 000 lb. per roller. Roller dimensions were 10 in. diameter by 1 1/2 in. contour radius.

The rolled axles were given a ground finish previous to rolling. The reduction in diameter due to rolling was 0.001 to 0.002 in. Axles other than those tested have been rolled using a smooth turned surface, and in such cases the reduction is 0.003 to 0.005 in. Since practically all this reduction takes place locally on the surface, the character of the machined surface controls the change in diameter due to rolling.

TABLE II. — **Summary of axle fatigue-test data.**

Axle No.	Wheel fit on axle, in.	Wheel mounting tonnage.	Axle bending stress., lb. per sq. in.	Life to failure.		Maximum depth of crack, in.
				Number of revolutions.	Equivalent miles.	
Unrolled nickel steel :						
9545 (*)	0.017	162	19 000	5 727 000	20 500	4 9/16
9540 (*)	0.016	152	14 000	19 850 000	70 600	13/32
9549 (*)	0.016	135	12 000	28 680 000	102 200	2 3/64
9550 (*)	0.016	170	10 500	83 730 000	298 000	1/16
Rolled nickel steel :						
9555 (*)	0.0135	178	19 000	143 470 000	510 500	7/16
9553 (*)	0.013	174	10 500	140 500 000	500 000	1/64
9554 (†)	0.012	192	19 000	48 500 000	172 800	...
9542 (†)	0.013	205	10 500	48 500 000	172 800	.

(*) Failed.
(†) Still being tested.

Table II gives a summary of the fatigue-test data for eight full-size axles. The illustrations of axle failures, all of which occurred within the axle fit, are shown in figures 3 to 8, inclusive. Some explanation may be necessary as to the manner in which specimens shown in figure 4 were obtained. A transverse slice was first sawed from the axle wheel seat containing the fatigue crack. This slice was then sawed into six pie-shaped segments, after which each segment was further sawed into the plane of the fatigue crack and the final separation developed by wedging apart the two portions of each segment through the saw cut. Therefore, figure 4 shows the saw-cut marks in the center of the axle, the area broken by wedging, and the fatigue crack developed in test

which may be identified at the outer circumference of the axle.

None of the full-size axles were run until the axle broke off in the test machine, although unrolled axle No. 9545, shown in figures 3 and 4 (left), was very close to this condition. The fatigue crack extended from the circumference practically into the hole through the center of the axle.

A comparison between the test results of rolled and unrolled axles for the same bending stress is shown in Table III. While both kinds of axles developed fatigue cracks, the depth and propagation of the cracks in the rolled axle is much slower than in the unrolled axle. At the high bending stress of 19 000 lb. per sq. in., the crack in the rolled axle is only one tenth as deep after about 25 times

Fig. 3. — Fatigue crack in the wheel seat of unrolled axle No. 9545.

Test axle No. 9545 of 3.1 per cent nickel and 0.24 per cent carbon steel, normalized and tempered. The bending stress at the inside hub face was 19 000 lb. per sq. in. The axle was tested to 5 727 000 revolutions to failure, which is equivalent to 20 500 miles on 72-in. wheels.

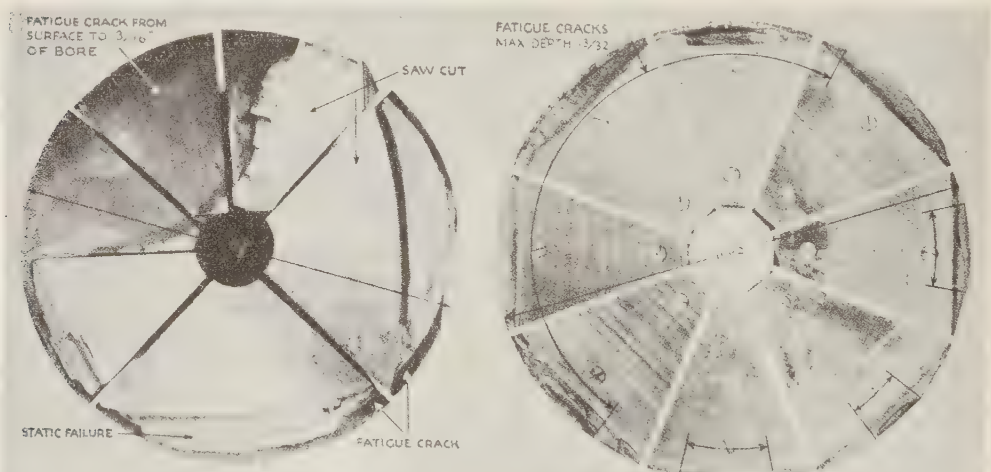


Fig. 4. — Depths of fatigue cracks in the wheel seat of unrolled axles Nos. 9545 and 9540.

Left : Depth of fatigue cracks in axle No. 9545 shown in fig. 3; compare the depth of this crack with that developed in the rolled axles tested at the same stress, but with twenty-five times the life, as shown in figs. 5, 6 and 7. — Right : Cracks developed in the wheel seat of unrolled axle No. 9450 near the inside hub face; this axle like all the others was of 3.1 per cent nickel and 0.24 per cent carbon steel, normalized and tempered. The bending stress at the inside hub face was 14,000 lb. per sq. in., and was tested to 19 850 000 revolutions to failure, which is equivalent to 70 000 miles on 72-in. wheels.

the life of the unrolled axle. At 10 500 lb. per sq. in., the rolled axle had a crack about one quarter as deep after about 1.75 times the life of the unrolled axle.

The previously mentioned tests on rolled axles are now in the process of being checked by axles running in the machines at the present time as indicated in Table II. While these check tests

TABLE III. — **Comparison of rolled and unrolled axles.**

—	Axle life		Maximum depth of crack, in.
	Revolutions.	Equivalent miles.	
Axle bending stress of 19 000 lb. per sq. in. :			
1. Unrolled	5 737 000	20 500	4 9/16
2. Rolled	143 470 000	510 500	7/16
3. Ratio of values in line 2 to those on line 1	25	25	1/10
Axle bending stress of 10 500 lb. per sq. in. :			
4. Unrolled	83 700 000	298 000	1/16
5. Rolled	140 500 000	500 000	1/64
6. Ratio of values in line 5 to those in line 4 .	1.7	1.7	1/4

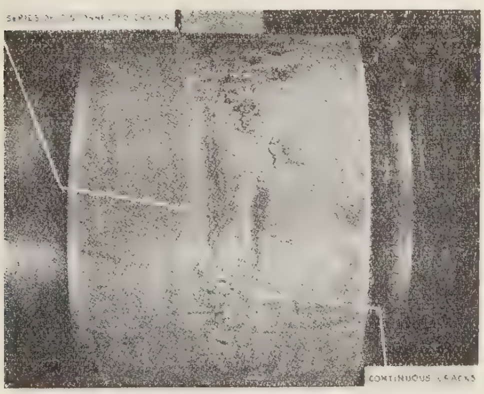


Fig. 5. — Fatigue cracks developed in the wheel seat of rolled axle No. 9555.

Text axle No. 9555 of 3.1 per cent nickel and 0.24 per cent carbon steel, normalized and tempered. The bending stress at the inside hub face was 19 000 lb. per sq. in. The axle was tested to 143 470 000 revolutions to failure, which is equivalent to 510 000 miles on 72-in. wheels. The fit of the axle was completely lost except for 2 in. near the center of the wheel seat, but the dismounting pressure was 600 tons with the rim of the wheel heated.

are not completed, they are sufficiently advanced to justify the feeling of similar improvement over unrolled axles.

The test of the rolled axle at 19 000 lb. per sq. in represents a very severe test and one which will not be equaled under any service conditions inasmuch as the wheel entirely lost its fit on the axle except for about 2 in. near the center of the fit. This loss of fit is due to a mechanical action of rubbing corrosion caused by the minute sliding or molecular attrition of the axle in the wheel fit occuring during each revolution. The mutilated surface of the axle wheel fit is apparent from figures 5 and 6 and even though only about 2 in. length of fit remained, 600 tons pressure was not sufficient to press the wheel off the axle at the end of the test. It was necessary to heat the rim of the wheel and at the same time press on the axle to dismount the wheel at 600 tons.

Figure 6 shows segments about 1 1/4 in. thick cut from the surface layers of the entire length of wheel seat of the axle shown in figure 5. These segments

Fig. 6. — Segments from the wheel seat of axle 9555, shown in fig. 5, bent slightly to open the cracks.

The fatigue cracks run circumferentially in the axle shown in fig. 5. The actual depths of the cracks are shown in fig. 7.

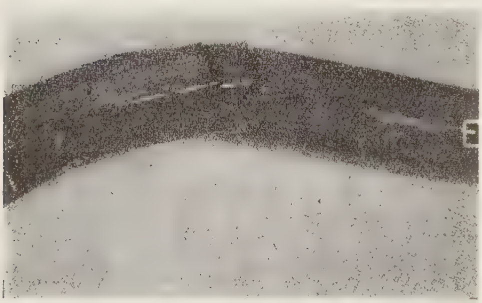


Fig. 7. — Maximum depth of cracks in axle 9555 shown in figs. 5 and. 6.

Maximum depth of cracks was 7/16 in. Note how the crack propagates at an angle of about 45 deg. with the surface. Compare these cracks with those in unrolled axle No. 9545 shown in fig. 4.

have been bent to open through the fatigue cracks. The depth of the fatigue cracks is indicated in figure 7. The development of the series of fatigue cracks shown in figure 6 and 7 instead of the usual single circumferential crack may be explained by the shortening of the wheel fit during the progress of the test.

The fact that the rolled axle also showed a crack at the low stress of 10 500 lb. per sq. in. checks with tests on 2-in. miniature axles which were run on a small machine similar in design to the one used for testing 11 1/2-in. axles. It was found that the incipient fatigue cracks in rolled axles develop at a stress which is about the same as, or slightly higher than, the stress at which they occur in unrolled axles, but these cracks propagate at a much slower rate in the rolled axles.

Additional tests are scheduled for rolled axles at much higher stresses than used previously to simulate the effect of a large number of occasional stresses of high value in service.

The practical value of the rolled axle is that considerably increased strength is obtained over the unrolled axle and

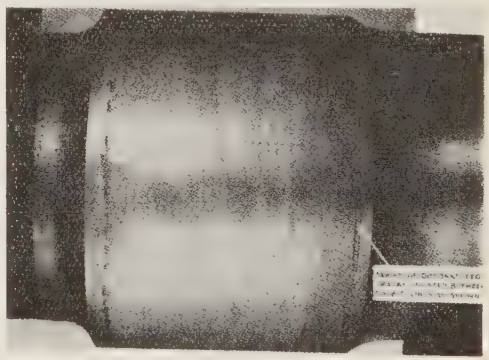


Fig. 8. — Fatigue cracks in rolled axle No. 9553.

Test axle No. 9553 of 3.1 per cent nickel and 0.24 per cent carbon steel, normalized and tempered. The bending stress at the inside hub face was 10 500 lb. per sq. in. The axle was tested to 140 500 000 revolutions to failure, which is equivalent to 500 000 miles on 72-in. wheels.

the liability of the axle breaking off in road service is reduced. As more test data are accumulated on full-size rolled axles, and if improved strength will be reflected comparable to that for 2-in. axles which were also tested, it is believed that the present typical mileage limit of 250 000 to 300 000 miles, at which driving axles are scrapped, may be increased to as much as possibly 500 000 to 1 000 000 miles, especially when rolling is combined with a higher raised wheel seat and possibly relief grooves in the hub of the wheel. The results of unpublished tests on unrolled axles, designed with a higher raised wheel seat than is reported in these tests, indicate that considerable improvement may be expected from this feature alone.

These tests on full-size locomotive driving axles are being continued and further progress reports will follow at a later date. It should also be mentioned that two additional axle-testing machines of the type shown in figure 1 are also in operation in the laboratory of the Timken Roller Bearing Company since December, 1937, on tests of 5 1/2-in. by 10-in. passenger-car axles. This latter programm is under the direction of the Association of American Railroads.

[656 258]

Route and approach locking,

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(Revue Générale des Chemins de fer.)

POINT, ROUTE AND APPROACH LOCKING.

Point locking.

At its origin interlocking (introduced in 1855 by Mr. Vignier on the old St-Germain Company's Line) was formed exclusively of interlocking combinations between *the levers* which worked the signals and points, and was merely intended to prevent, by material means, a signalman from giving permission to conflicting train movements, which might foul one another, to take place at the same moment. In practice, interlocking of this kind is quite sufficient to prevent any accident of that nature, at least at signal boxes whose zone of action is not large. It is clear, for example, that in figure 1, the interlocking between the levers of the absolute stop signals 1 and 3, which prevents them from being set at « line clear » simultaneously, is sufficient in practice to prevent any train from fouling another at the point A. The signal 3 being cleared prevents the signalman from clearing signal 1 by mistake. When the train has

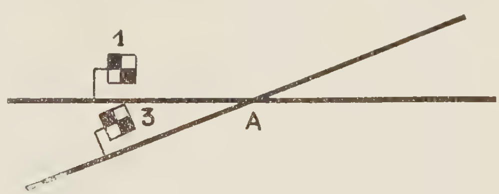


Fig. 1.

passed, the restoration of signal 3 to danger suffices to liberate the lever of signal 1, but, in practice, the first train has completely passed the point A, if not when the signalman has cleared signal 1, at least before any train approaching under that signal has had time to reach point A.

If now, as shown in figure 2, we consider a zone including points, which is the case usually met with, we at once meet with a difficulty. When a train passes signal 3 at « line clear » with

Fig. 2.

points 2 set for the diverging line, the interlocking compels the signalman to first put that signal to danger before he can reset points 2 to the normal position. This, however, is not enough. Nothing prevents the signalman, after returning signal 3 to danger, from at once resetting the points while the train is passing over them. This would lead to the tongues being damaged, at least if — as is usual in France — the points are not trailable.

If now we consider the case of points run over in the facing direction, as in figure 3, we see that the position is much more serious. The lever of stop signal 1 and that of points 5 are interlocked in such a way that the clearing of the stop signal locks the points, in

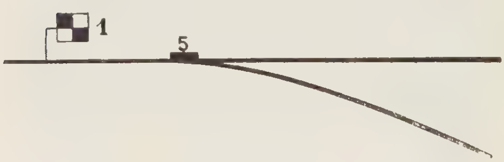


Fig. 3.

either position. The replacement to danger of the signal, however, frees the point lever, and should the signalman try to move it by mistake during the passage of the train there would be a derailment and not merely some damage to the points.

It was therefore useful, even at signal boxes having a small zone of action, not to be content with interlocking between levers, but to add to it some device to make it materially impossible to move points while a train was passing over or standing on them.

At first this result was obtained with the aid of so-called *mechanical lock bars,* which had the disadvantage of making the working of the points much heavier. In addition, since the appearance of bogie vehicles it became more and more difficult to give these bars a greather length than that between two successive pairs of wheels, which was obviously necessary to prevent with certainty any moving of points under a train.

Hence, for a long time now, mechanical lock bars have given place more and more to insulated rail sections adjacent to the points. These are short track circuits, of whatever length desired, the occupation of which by a vehicle short-circuits a relay, which has to be energised in order to free an electric locking device which holds the points in either their normal or their reversed position. In this way the false movement of points under a train is prevented much more satisfactorily than it is with mechanical lock bars.

Route locking.

Such locking of points under a train, even if limited to facing points, suffices in practice at signal boxes controlling a limited area, but in those controlling a large area it becomes altogether insufficient, especially in power signal boxes working on the route lever system, in which the reversal of a single lever by the signalman is sufficient to set all the points in a route, however complicated, and to clear the signal authorising a train to enter that route. Such signal boxes offer very great advantages, especially from the fact of the great rapidity with which they allow the train move-

ments to be regulated. If, however, special precautions were not taken this very rapidity would make it relatively easy, should the signalman make a mistake, to move points at the wrong time in the face of an approaching train. These precautions generally consist of what is called *route locking.*

This term denotes an arrangement which locks all the points constituting a given route from the moment when the train passes the stop signal controlling access to that route until it has passed completely out of it. This is generally accomplished in a simple manner, by locking the route lever (1) in its reversed position (2) (in which it mechanically locks the controlling elements of all the points concerned) by an electric locking device, the current to which is cut off all the time the train is travelling over the route. The current is cut off when the train *reaches* a treadle at the beginning of the route, adjacent to the relative stop signal, and restored when it has passed completely over a *releasing* or exit treadle beyond the last pair of points in the route. The locking of the route lever in its reversed position provides indirectly the locking wanted on all the points in the route.

Safety is thus absolutely ensured. Nevertheless, although this system may in practice possess no disadvantage at those signal boxes where the trains merely run straight through, it becomes decidedly hampering at others, where numerous shunting movements have to be made. Let us examine, for example, the station illustrated in figure 4.

When, for example, a train has to start from track 5 for A, the signalman reverses route lever 5A, thus clearing signal 5. The train leaves and as soon as the locomotive passes the signal the route locking prevents the signalman from restoring lever 5A to normal, so locking the points 2, 4, 6, 8, and 7 in the positions they occupy to form route 5A. This locking is released, so freeing the route lever and hence the points, when the train has passed *completely* clear of the last pair of points, points 7 in this instance. As a rule this is not found burdensome when a running departure movement is taking place, but it can become altogether inadmissible where certain shunting movements are concerned. Let us suppose that, before starting, the

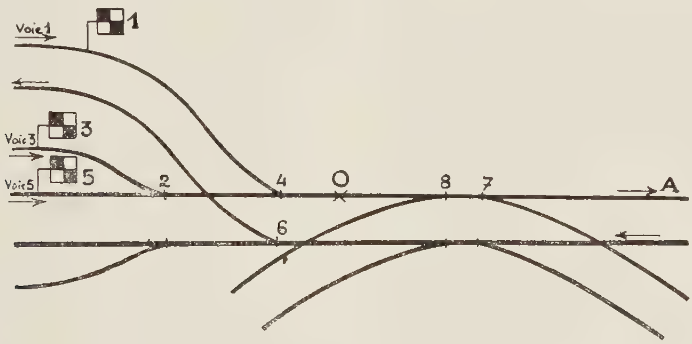


Fig. 4.
Note. — Voie = track.

(1) Or the lever of the stop signal itself, in a signal box operated on the individual lever principle.

(2) The protection of the train against a following one on the same route is obtained by replacing the stop signal to danger automatically or (in French signal boxes), by automatic placing to danger of a block semaphore.

train standing on track 5 has to take up in rear a vehicle standing on track 3. As in the case of the ordinary departure movement, the signalman clears signal 5 in setting up the route 5A. But it is obviously unsatisfactory for the train to have to *pass clear* of points 7 before the signalman can return the route lever 5A to normal and reverse points 2 with the aid of route lever A3. It is therefore necessary — at least if such shunting movements are at all frequent, as they are in the majority of large stations — to make the route locking, as above defined, more flexible.

Different means of doing this have been used :

(a) It is possible to free the route locking, properly so called, that is to say the locking on the route lever in its reversed position, when the train *reaches* the excit treadle (*) and not when it passes clear of it [3]. In the case of figure 4, this would permit the shunt movement to stop short of passing completely over points 7 and to stop directly its locomotive reached those points. This saves the movement from going a distance equal to its own length. This is an improvement, but far from perfection. It is clear that it only affords an insignificant advantage, compared with complete route locking, in the case where the movement we are considering consists in putting the vehicle on track 3, to be taken up, at the head of the train; the locomotive would thus only gain twenty yards or so, which is insignificant.

(b) It is possible to divide up the routes. For example, in the case of figure 4, route 5 A may be replaced by two, 5 O and O A. To set up route 5 A the signalman first reverses lever O A, then lever 5 O. Each of these half routes has complete through route locking, so that in the case of the shunting movement under consideration, the train of vehicles has only to clear the point O to enable the signalman to restore the lever 5 O, and reverse points 2 by pulling route lever O 3, points 7 and 8 remaining locked by the route locking on the half-route 0 A.

This certainly does represent an improvement, but falls far short of perfection. On the one hand, we have increased the number of route levers [4]; on the other hand, shunting movements from track 5 to track 3 must still clear the point 0, although it is desirable that they should be able to stop immediately beyond points 2.

(c) It is equally feasible, while keeping to one lever for the whole of the route 5 A, to give the signalman a route locking cancelling device to meet the case of shunting movements. Such a device can take several forms. It often consists of a lever the reversal of which, while directly locking the points at the end of the route, such as points 7 and 8 in figure 4, cancels the route locking holding lever 5 A reversed, and so makes it possible to manipulate one of the points in the first part of the route, such as 2 and 4 in figure 4. As in the preceding proposal, this also has the disadvantage of increasing the number of levers.

(d) Finally, it is possible to accomplish route locking by means of the so-called « flexible » arrangement, which, from the operating point of view, is cer-

(*) The term « treadle » (pédale) is used here, as is often the case in French descriptions, to mean a length of insulated rail.

(3) This evidently requires that each pair of points shall include an insulated section, the occupation of which will directly lock the controlling element, while in a signal box having integral route locking, described above at the outset, such sections on the points have often been eliminated to save expense.

(4) It is true that sometimes routes are divided up, or sectionalized, for other reasons, and actually for the opposite purpose of reducing the number of route levers.

tainly the best solution of the problem, since it does *not* offer any hindrance to the working of the traffic. It does not necessitate the addition of any levers or cancelling devices and the signalman works exactly as if no route lock existed. The apparatus only comes into play if the signalman commits an error, to prevent any grave consequence resulting therefrom.

In this system the route lever does not itself have any locking device and may, in consequence, be restored to the normal position immediately the locomotive passes the stop signal. From that moment, however, *all* the points in the route are locked, and are released one by one in turn, as the last wheel of the train passes clear of them. Thus, in the case of figure 4, when the signalman wishes to make a shunting movement from track 5 to track 3, he can restore signal 5 to danger by returning the route lever 5 A as soon as the locomotive has passed that signal. Points 2 are then only held by the route locking; as soon as the vehicles have passed clear of them they can be reversed by operating lever A 3.

Such a result can be obtained in various ways. Readers who are interested in the question will find appended to the present article a working diagram showing the principles of the arrangement worked out by the « Société d'Electricité Mors » and applied in some signal boxes recently installed on the Western Area of the French National Railways, especially at Caen in 1934, and Le Mans in 1936. This flexible system of route locking has given complete satisfaction and the Western Area intends to apply it systematically at all large signal boxes where complicated shunting movements occur. It was likewise installed in 1935 in the signal boxes at Sotteville, and in 1938 in those at Lisieux and Mézidon, where the Thomson-Houston Company effected it under conditions slightly different from those found at Caen and Le Mans, but nevertheless proving equally satisfactory.

* * *

Approach locking.

Route locking affords complete security against a mistake made by a signalman while a train, which has passed the stop signal, is still within the area containing the points controlled from the signal box. Such a mistake, however, is not the only one a signalman might make and we have also to consider the following possibility, illustrated by figure 5.

A signalman sets up the route A B, clears stop signal 7, the corresponding distant signal 1, the reduced speed signal R 1, and the reduced-speed reminder signal R R 1, points 2 and 1 being in their normal position, as shown by the heavy lines in the figure. For some reason or other he changes his mind, can-

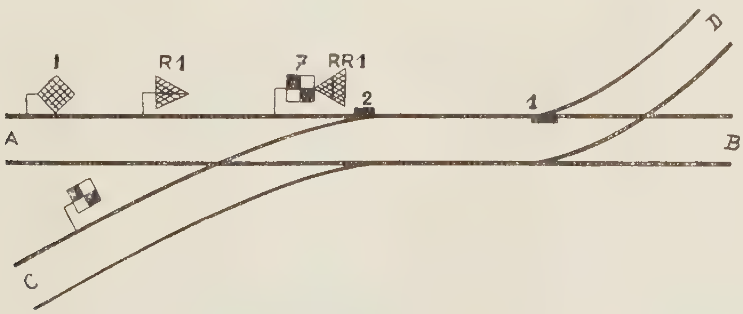


Fig. 5.

cels the route A B by restoring the signals to danger and sets up some other route. No disadvantage arises from this if there is no train travelling between signals 1 and 7, but if, however, there is one between the group of signals 1 and R 1, which it has passed at « line clear » and the stop signal 7, clearly an accident might occur.

If the signalman, after having cancelled the route A B, has set up the route C B, the train will encounter the stop signal 7 at danger. The driver having passed the distant signal 1 at « line clear », will generally be unable to pull up at the stop signal. He will not only over-run that signal but also run through points 2, which have been set for the route C B, and will burst the tongues. In addition the train will in all probability stop in the neighbourhood of points 2 and 1, where there is a risk of its being run into by the other train following the route C B.

If, on the other hand, the signalman sets up the route A D after cancelling route A B, we have the risk of another kind of accident. The train, having passed the reduced-speed signal R 1 in the « off » position will generally be unable to observe the speed restriction called for by the reduced-speed reminder signal RR 1 and runs the risk of being derailed through taking points 1, set for the diverging route, at too high a speed (5).

In order to prevent such accidents the regulations instruct the signalmen, should they have set up and cancelled a route without any train having passed, not to alter the position of the points until they have waited long enough to be practically sure that no train has already passed the distant signals in the « off » position. These rules are, however, of purely moral value and there is evidently interest in replacing them by some material means of compelling obedience to instructions. The name of « *approach locking* » is given to any apparatus of the kind.

As with route locking, approach locking may be accomplished in several different ways. It generally consists of two treadles — an « entering » treadle placed in rear of the distant signal, and a « leaving » one, situated ahead of the stop signal —, or of track circuiting between those two points. The presence of a train, which has passed the distant signal in the « off » position, between the two treadles, or on the track circuit, makes it absolutely impossible to interfere with any of the points in the route set up.

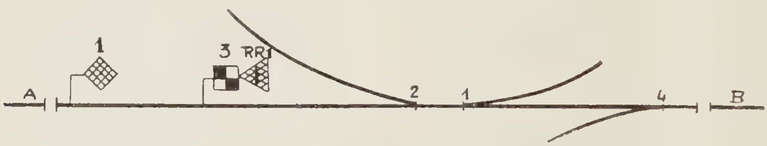


Fig. 6.

Approach locking can with advantage be combined with flexible route locking — or sectional route locking, as it is called — in the conditions illustrated in figure 6. The line is completely track circuited from point A, in the rear of the distant signal 1, to beyond the last pair of points 4. If a train approaches without any route being set up for it, that is with signals 1 and 3 « on », all points in the route are free and the signalman can operate them at will.

(5) We may note in passing that the recent introduction of the reduced-speed reminder signal in French signalling has considerably increased the safety at such a layout, from this point of view.

Let us suppose, however, that the signalman has cleared signals 1 and 3 before the train arrives, and has reversed the route lever A B. The last mentioned movement evidently prevents him from altering the position of points 2, 1 or 4 by the reversal of a route lever conflicting with A B. As long as a train has not reached the point A, where the approach locking section begins, the route lever remains free and nothing prevents the signalman from restoring it to normal and setting up another route in turn.

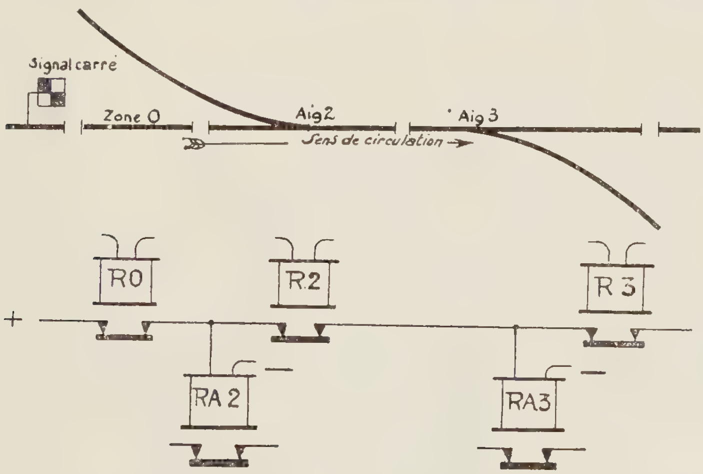
If, however, a train should pass A while route lever A B is reversed, the latter at once becomes locked in that position. The signalman cannot therefore make the mistake of showing the stop signal at danger to a driver who has passed the distant signal « off » (6). *A fortiori,* the signalman is powerless to alter the position of any points in the route set up. The head of the train passes the stop signal 3 « off »; the approach locking at once ceases to act, even though the tail remains between the signals 1 and 3, and nothing now prevents the signalman from putting 3 to danger by restoring route lever A B to normal, but at the instant when the approach locking is released the flexible route locking comes into play, locking the points in the route directly, to be freed in turn as above explained, as the train passes clear of them.

In this way the maximum degree of security is obtained, without the working of stations being hampered in any manner.

Diagram showing the principle of flexible, or sectional, route locking.

(MORS system.)

The line is track-circuited throughout the area controlled from the signal box. (It has been the practice to instal the sectional route locking simultaneously with the automatic block, which itself



Figs. 7 and 7b.

Note. — Signal carré = stop signal. — Zone = track circuit section. — Aig = points. Sens de la circulation = direction of traffic.

(6) Of course, the signalman has an « emergency switch », permitting him to throw the stop signal to danger in exceptional circumstances, should this be necessary; for example, in consequence of the clearance being fouled through a derailment on an adjacent track.

requires such track circuiting.) Each track circuit section comprising a pair of points (fig. 7) has, in addition to the usual track relay, R 2, R 3... (fig. 7*b*), energised or not, according to the condition of the section, an auxiliary relay RA 2, RA 3...

The feed to any one of these auxiliary relays passes over top contacts on the track relays for each section in rear of the pair of points in question. Besides this, each pair of points is positively locked in whatever position it happens to occupy unless *both* relays relating to it are simultaneously energised.

It is easy to see how this arrangement works. The stop signal being « off » and all the track circuit sections clear, all relays are energised, the various points in the route only being locked indirectly by the fact that the reversed route lever mechanically locks their controlling units. The train arrives : as soon as its first wheel reaches section 0, immediately in advance of the stop signal, relay R 0 is de-energised, causing the immediate de-energisation of all the auxiliary point relays R A 2, R A 3... All points in the route are therefore locked by their auxiliary relays.

When the train reaches section 2 and is occupying sections 0 and 2 together, relay R 2 releases its armature and points 2 still remain locked, because relays R 2 and R A 2 are de-energised at the same time.

When the train clears section 0, section 2 still being occupied, relay R 0 picks up, causing relay R A 2 to do the same, but points 2 remain locked by re-

Fig. 8.

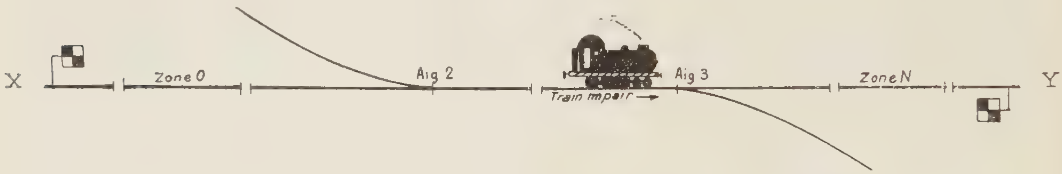
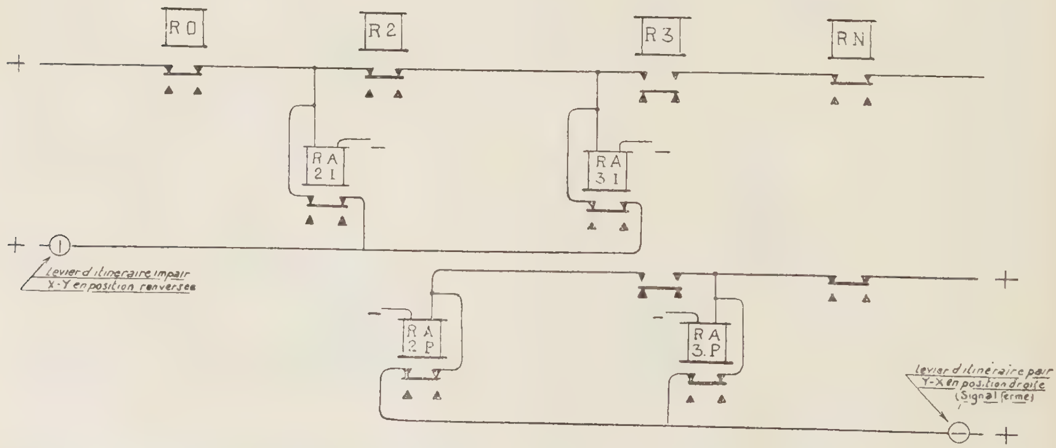


Fig. 8bis



Figs. 8 and 8*b*.

Note. — Train impair = down train. — Levier d'itinéraire impair en position renversée = route lever for down direction in reversed position. — Levier d'itinéraire pair en position droite (signal fermé) = route lever for up direction in normal position (signal « on »).

lay R 2. Finally, when the train clears section 2, relay R 2 picks up in turn and all locking on points 2 is released.

The matter becomes somewhat more complicated if the route can be traversed by trains in both directions. In that case each pair of points has, in addition to its track relay, two auxiliary relays (figs. 8 and *8b*), one, R A 2 1, to provide route locking for down line movements, the other R A 2 P, for up line movements. A pair of points is then locked by the de-energisation of *any of its three* relays.

This alone is evidently not sufficient.

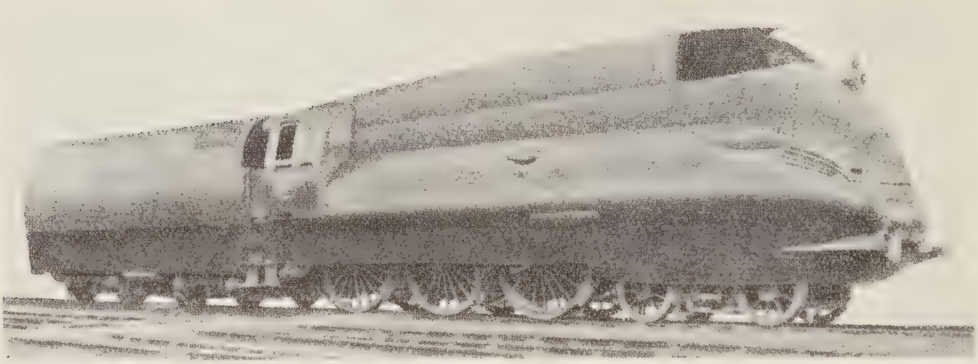
If we consider the case of figure 8, and assume that a movement in the down direction has passed clear of sections 0 and 2 but is still in section 3, we then require points 2 to be free. For this it is necessary that all three relays concerned shall be energised. Relay R 2 is so, of course, since section 2 is clear; relay R A 2 1 is energised also (fig. *8b*) through the circuit passing over the top contacts relating to section 0, itself clear, situated in the rear of section 2 for a movement in the direction under consideration. If, however, relay R A 2 P, corresponding to the up direction of traffic, could only be energised through the top contacts of sections N and 3, situated in rear of section 2 for up movements, it would now be de-energised, because section 3 is occupied, and the final result would be to leave the points 2 still locked. Actually each of the up auxiliary relays R A 2 P, R A 3 P,... is held energised during a down movement by a stick circuit (fig. *8b*), taken over a contact closed when the route lever for the up direction is normal. In this way the desired result is obtained; as soon as section 2 is cleared points 2 become free and nothing prevents them from being reversed to allow the train to shunt back.

MISCELLANEOUS INFORMATION.

[621. 132.3 (.44) & 621. 392 (.44)]

1. — Four-cylinder compound 4-6-0 engines of the former French State Railways rebuilt with external and internal streamlining and welded cylinders.

(*The Railway Gazette.*)



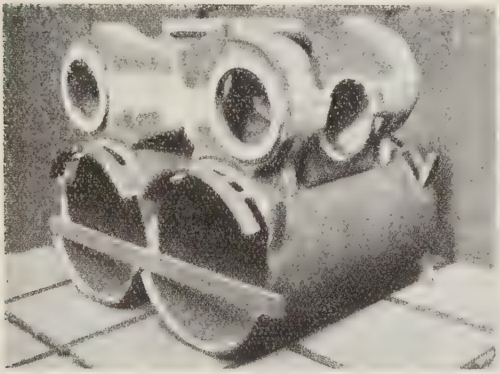
The need of a locomotive to haul light, fast trains, led the former French State Railways to rebuild a number of old 4-6-0 type engines, originally built some 30 years ago. The reconstruction is of interest, not only because of the remarkable performance characteristics of which the locomotives are now capable, but also on account of the first use on so important a scale of welded cylinders.

It is intended that the locomotives shall replace others of the 4-6-2 type for light trains, to do which the main problem was that of increasing their power output. The boiler pressure of the rebuilt locomotives is 210 lb. per sq. in., and the whole of the steam flow and distribution system and cylinders have been altered. Dabeg poppet valves being incorporated. The ratio of the volume of the high pressure to the low pressure cylinders has also been increased. The boiler has, moreover, been provided with an enlarged superheater providing steam at about 800° F.

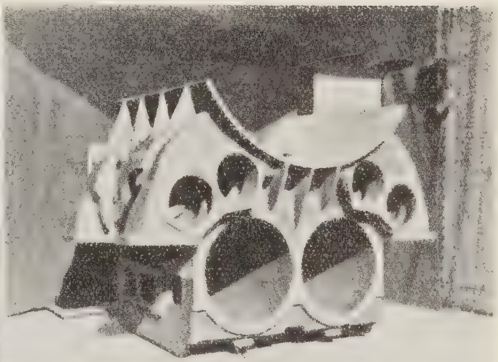
A plan for making these cylinders in cast steel had been worked out by Société Dabeg, but as the time required for their manufacture was too great, this idea was abandoned in favour of fabricating by welding, after studying the results of two previous experiments in this type of cylinder construction. One of these had been carried out by the P.O. Railway in France (*), and the other by the L. M. S. R. in England (†); in neither case, however, had a completely welded construction been tried. The thickness of the metal was the same as that originally planned for the cast steel cylinders, and only for certain parts, in which welded construction presented extreme difficulty, was cast steel used, na-

(*) *The Railway Gazette* of January 28, 1938, page 178. See also *Bulletin of the Railway Congress*, August 1938, p. 836.

(†) *The Railway Gazette* of May 18, 1934, page 878. See also *Bulletin of the Railway Congress*, September 1934, p. 999.



Welded cylinders and valves under construction.

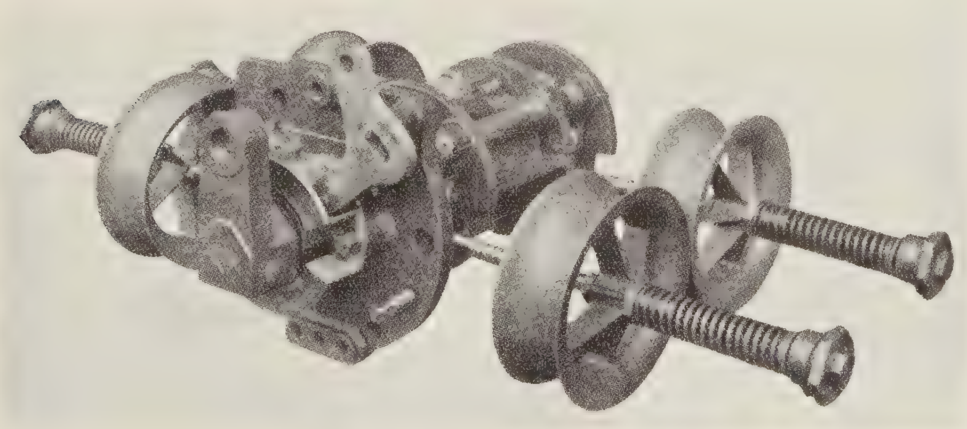


Welded l.p. cylinders and smokebox saddle.

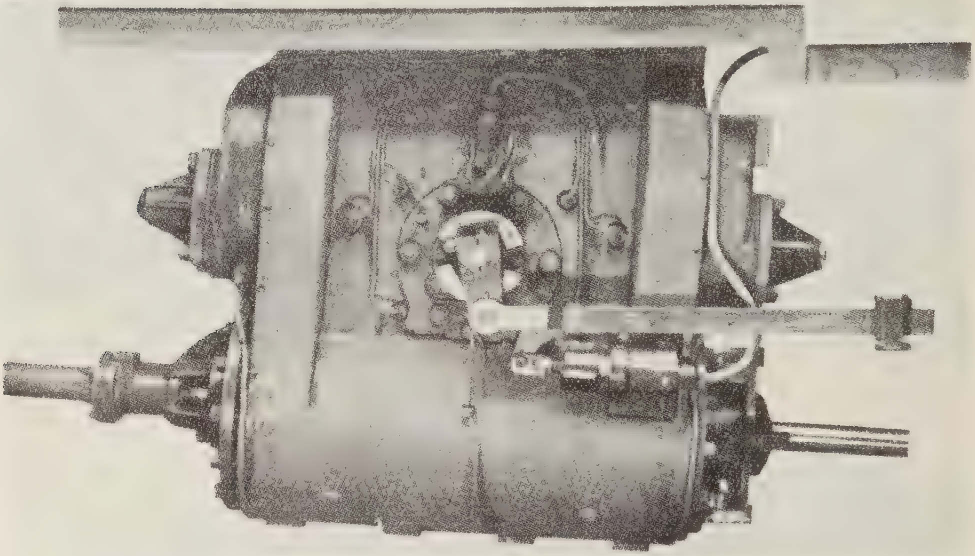
mely, for the ports of the low pressure cylinders, and for the admission ports of the high pressure ones.

The endeavour was to minimise stresses at the welds, and the whole was annealed after completion, so that such stresses as there were were largely removed; it was, however, considered important that they should have been virtually eliminated before annealing, so that there should be no danger of incipient fractures. The low pressure cylinders were divided for constructional purposes into several parts; the cylinders proper, the steam-chest, the exhaust port, and the two-part cam case. Apart from these, the inside cylinder block includes the smokebox saddle. All these parts were built up separately so as to obtain easily accessible welds, and the whole assembly finally welded together. This form of construction, and the need for steam-tightness, led to the use of a cast steel exhaust port with a web on the surface which is in contact with the cylinder wall. The danger of leaks in the weld was thus reduced.

It was considered advisable to machine certain of the parts before welding, not only



Dabeg poppet valve cam case and gear.



Outside poppet valve cylinder of welded construction.

to reduce the amount of machining required after completion, but also to reduce the risk of bad contacts between parts during welding. The various parts were cut out by oxy-hydrogen cutters, and any roughness removed by milling before welding. The assembly was carried out in sectional formation.

Thus the base of the cylinders forms one section, the cylinder walls with their connecting webs another, the cam cases a third, and so on. Every section was assembled and then tested to ensure that there was no deformation. The final assembly of the parts could then take place and the whole piece be machined in the ordinary manner.

The welding was done with a d.c. welding machine, and wherever possible with the pieces lying flat. The electrodes used were Fusarc 45. After welding, the whole was annealed at 650° C. This temperature was reached in five hours, maintained for two hours, and the piece then allowed to cool for 12 hours. The cost of the cylinders, of which only a limited number was to be made, was about half that of similar cast steel cylinders, and of a mechanical strength at least equal to that of the cast steel. The time required for the construction was about half what would have been needed for a cast steel cylinder.

[656. 254 (.42)]

2. — Results with Hudd system of automatic train control on the London Midland and Scottish Railway.

(*Modern Transport.*)

Permanent and electro-magnetic inductors on track, 200 yards in advance of distant signal, Upminster and Southend line, L.M.S.R.

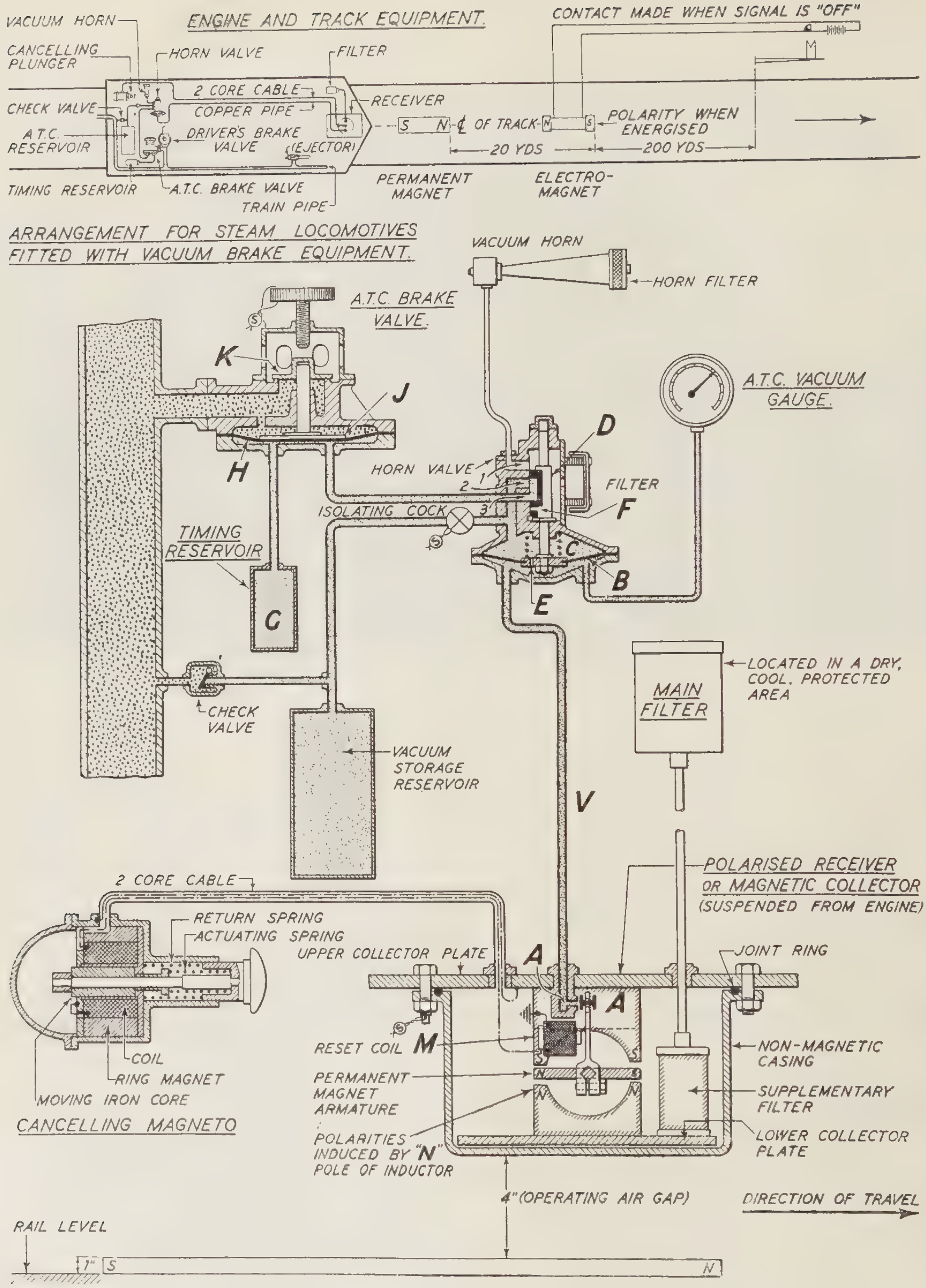
Considerable impetus was given to the development of a satisfactory automatic train control system by the report of the Automatic Train Control Committee, summarised in our issue of December 6, 1930. In that report favourable reference was made to the Hudd system of intermittent inductive control, and certain tests performed on an adaptation of the Strowger-Hudd system installed at Byfleet on the Southern Railway were described in *Modern Transport* of September 19, 1931 (1).

Six years ago the London Midland and Scottish Company began experimenting with the Hudd system, and by courtesy of Mr. A. F. BOUND, signal and telegraph engineer. L.M.S.R., we recently had the opportunity of inspecting the apparatus which is giving satisfactory performance an the Southend line. Some 36 3/4 route (or 73 1/2 track) miles have been equipped between Gas Factory Junction and Shoeburyness viâ Upminster, 112 signal locations being fitted with the Hudd inductors. At present there are 32 locomotives fitted with the latest form of apparatus, and the work of equipping another 80 is in hand. It will thus be possible to conduct full-scale experiments this winter with all the locomotives stationed at Plaistow, Tilbury and Shoeburyness sheds normally working the line.

Ground apparatus.

The equipment is intended to provide a warning to the driver about 200 yards before reaching a distant signal. If the distant signal is « off » a horn blows for 1-1 1/2 seconds but if it is « on » the horn continues to blow until cancelled by the driver. Three seconds after the horn begins to blow a progressive brake application commences, this being ar-

(1) See also *Bulletin of the Railway Congress*, February 1932, p. 157.



Above, layout of Hudd automatic train control system, and, below, diagram showing locomotive receiver armature holding valve button A away from the orifice at moment vacuum in pipe V is about to be destroyed. Parts of the system lightly shaded are normally under 21-in. vacuum maintained from storage reservoir; heavily dotted area is under 21-in. train pipe vacuum.

ranged so as to bring the train to a standstill at the home signal, even should the driver leave the regulator fully open. After acknowledging the horn by pressing the cancelling plunger the driver must, if necessary, take the brake application into his own hands.

The apparatus on the ground comprises, first, an Alnico steel permanent magnet, weighing 40 lb., the south pole being approached first by the train, and the north pole lying in the direction towards the distant signal. Twenty yards nearer the distant signal (10 yards in future installations) an electro magnet is placed, and this is arranged to be energised when the distant is « off ».

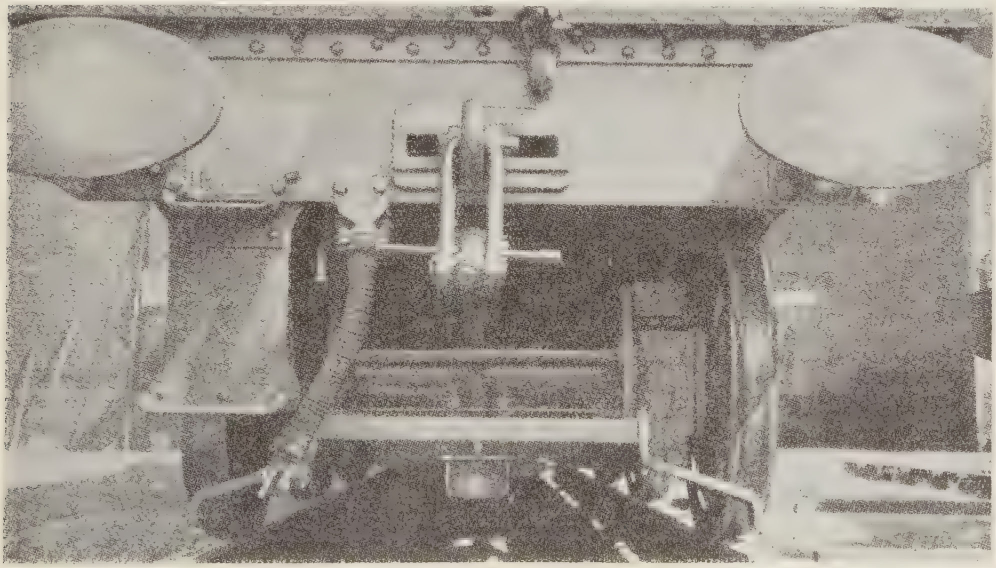
Current supply.

Both magnets, or inductors, are fixed in the centre of the 4-ft. way. The electro-inductor when energised is of reverse polarity from the permanent inductor, the engine passing over the north pole first and the south pole second . The electro magnet of the second inductor is wound to a resistance of 16 ohms, and works on 12 volts. Where a power supply is available in the district, current is supplied by a trickle-charged battery floating on the supply. In open country where no power is available, current may be supplied from a battery, and economised by an open-circuit track circuit with two insulated lengths of rail at the inductor, the first to put the current on the inductor and the second to act as cut-off as soon as the engine has passed it.

The inductors have their top surfaces 1 in. above rail level, the receiving apparatus on the locomotive being 5 in. above the surface of the rail. There is thus a 4-in. operating gap, but the setting of the apparatus on the locomotive is not critical, it being capable of working effectively with an 8-in. gap, giving, as the strengths of magnetic fields vary on the square law, a factor of safety of more than four.

The locomotive receiver.

The receiving apparatus on the locomotive comprises a permanent magnet with an ar-



View showing suspension of automatic train control receiver below locomotive in the Hudd inductive system as used on the Southend line of the L.M.S.R.

mature of 35 per cent. cobalt steel, approximately 2 in. square by 1/8 in. thick. It is carried in small ball bearings packed in non-freezing grease. The armature lies between soft iron pole pieces, of which the horns extend round it, and it is a « stick » armature, magnetic bias maintaining it to one side or the other. Carried on the armature spindle is a short lever with a forked end; a small stainless steel valve button floats loosely in the fork, and normally rests to close a small orifice of a vacuum pipe from the cab of the locomotive.

When deflected by the north pole of the permanent inductor in the track, the orifice is opened, while should the distant be off, the south pole of the electro magnetic inductor deflects the armature back to normal and closes the vacuum pipe. The entry of air into the automatic train control vacuum system through the orifice thus produces a momentary blast on the horn in the case of the distant being off, or since there is then no south pole at the electro inductor to return the stick armature to normal, causes a continuous blast if the distant signal should be on. The method of operation of the horn and the production after a few seconds of an increasing brake application when the distant signal is on is as under. When valve A in locomotive receiver is opened (as shown on the diagram) by movement of the armature on passage over a north pole, the vacuum in chamber B of the horn valve is reduced to 3 in., while that above the diaphragm in chamber C is at the normal 21 in.. This causes slide valve D to rise sharply, and instead of ports 2 and 3 remaining in communication at the same degree of vacuum, ports 1 and 2 are connected. Air enters the system connected with the vacuum storage reservoir or the miniature ejector through the horn, which is thereby sounded.

If the distant signal is giving a clear indication the receiver next passes over the trailing south pole of the electro inductor, the armature is restored to normal and valve A in the receiver is closed. The diaphragm between chambers B and C of the horn valve is pierced by a small pilot feed hole E, through which vacuum is restored to chamber B. Spring pressure restores the slide valve D to normal and the horn is cut off after emitting sound for just over a second.

Caution indication.

If the distant signal is at caution the electro-inductor is not energised and valve A remains open after passing over the north pole of the permanent magnet. Not only does the horn sound continuously, but a progressive brake application is obtained in the following way : When ports 1 and 2 in the horn valve are in communication, port 3 is aligned with orifice F in valve D. This is in communication with the atmosphere through the filter alongside the horn valve chamber, and as a result the vacuum in the timing reservoir G is gradually reduced.

The balance between chambers H and J in the A.T.C. brake valve is thus upset, and the diaphragm is forced up, lifting valve K and admitting air to the train pipe. The application is automatically adjusted to the length of the train, being reduced for a light engine and amplified as the volume of the train pipe increases. The action of the timing reservoir destroyed the train pipe vacuum in 22 sec. whether connected only to the locomotive train pipe or the equivalent of a 13-coach train in the demonstrations we witnessed.

Cancelling device.

A considerable amount of research has been devoted to the production of a reliable cancelling device in order that the driver may be able to acknowledge the indication that he has passed a distant signal in the « on » position, and take the subsequent brake application into his own hands. It was considered highly desirable to avoid the complication of electrical apparatus involving batteries on the locomotives, and the alternative of vacuum or air-pressure cancelling did not prove entirely reliable in service. A hand-plunger magneto was then evolved; a momentary impulse current is sent and this restores the armature through reset coil M and so blocks the orifice to vacuum pipe V

and shuts off the horn. The cancelling magneto comprises essentially a ring magnet polarised on each face. The plunger, when pressed, compresses the outer return spring and also an assisting spring which projects the soft iron core of the plunger through the ring magnet at the same speed no matter how the pressure is applied to the plunger. This arrangement affords the minimum of parts to require maintenance.

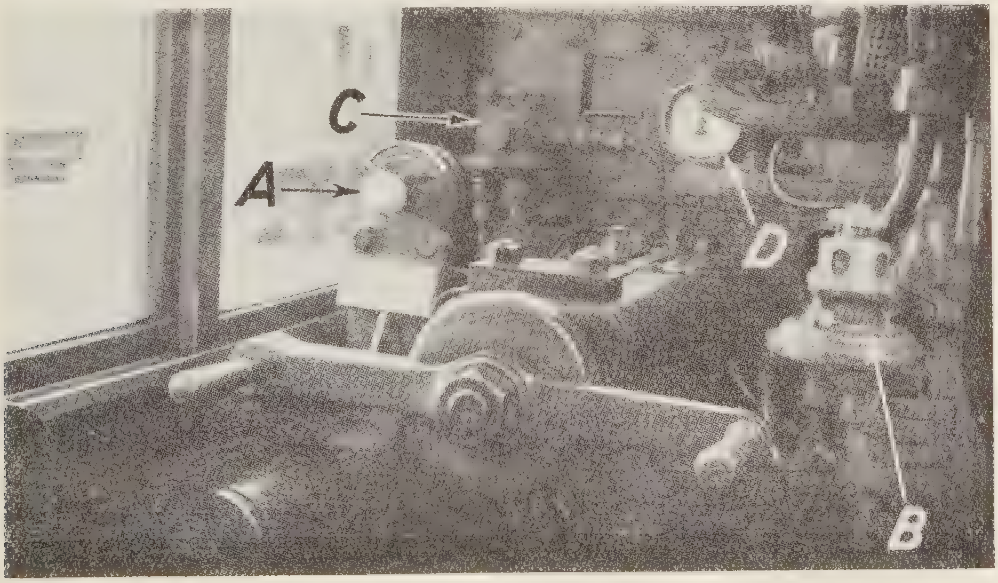
Wrong line working.

When a locomotive receiver passes over the inductors in the wrong direction, as in the event of wrong line working, the deflection of the armature by the north pole of the permanent inductor is immediately followed by its restoration by the south pole, so that the device is then self-cancelling and even at slow speeds the blast on the horn is sounded for only a fraction of a second, but at normal running speeds there is no sound.

The inductors are provided on the Southend line at a number of intermediate block posts, and are, of course, worked from the arm in the case of motor-worked signals. All signals will be provided with a contact-box on the arm, in addition to the contact on the lever, but this has been omitted from the diagram reproduced for the sake of clarity. In the case of combined home and distant signals on one post it is L.M.S. practice to give the location warning at the standard distance from the signal, in order that drivers may have the required braking distance available.

Means are provided under seal for cutting out the A.T.C. apparatus in case of casualty, when, of course, it would be necessary for the enginemen to report the locomotive at once. For freight working by engines fitted with the steam brake, on which a driver may omit to blow up a vacuum, a miniature ejector is provided as a source of vacuum in order to obtain an A.T.C. indication.

Although the steam locomotive stock generally is vacuum-fitted, on the London, Tilbury and Southend section of the L.M.S.R. there are eleven dual-fitted locomotives equipped



Equipment for Hudd automatic train control in locomotive cab, showing cancelling magneto, A; a.t.c. brake valve, B; horn valve, C; and vacuum gauge, D.

also with the Westinghouse air brake for working District Line trains to and from Ealing Broadway (London Passenger Transport Board), and these will be equipped with an adaptation of the apparatus to the Westinghouse brake. The equipment is also available for working with the electro-pneumatic brake on multiple-unit electric trains. A number of the engines already equipped regularly operate over fourth rail electrified lines, and experiments show that the Hudd system can be satisfactorily applied with third rail or overhead electric traction.

The cover surrounding the receiver is of stainless steel (in future bronze will be used), and is strong enough to protect the apparatus from all normal damage. The receiver is bolted to the locomotive by bolts weak enough to yield in the event of accident, so preserving intact the receiver apparatus. No damage to the fixed apparatus has been experienced on the Southend line, but ramps would be necessary to protect the inductors against damage from hanging water scoops when traversed by main line locomotives. Precautions have been taken to make the fastening of the inductors so secure that they cannot be stolen from the track for the sake of the magnet steel or the value of the copper.

Maintenance.

The policy has been to refrain from maintaining the apparatus on the locomotives in order to discover where faults were likely to arise, but satisfaction has been given in service. The receiver is absolutely watertight, no leak being experienced even when placed under water for twenty-four hours with 21 in. of vacuum on the equipment. It has also been found proof against freezing when the metal parts of the receiver were maintained at 10° Fahr. below freezing point, and also in the possibly more onerous conditions just below freezing-point. With the air temperature at that level the intake pipe has been placed just over a steaming water bucket, and no trouble in the operation of the apparatus has been experienced. Vokes filters are provided on the locomotives to keep the receiver apparatus free from dust. These are indicated on the diagram, and the main air inlet is kept in a cool, dry and protected place.

In ordinary practice signal and telegraph linemen would attend to the ground apparatus, which has been carefully maintained throughout the present series of experiments. The locomotive receiver is designed to be maintained by the shed fitter. For this reason the cable from the cancelling magneto to the receiver is provided with single pin connections inside a pipe joint type of connector with a union nut which forms the other pole. It can be tightened by a spanner in the ordinary way. The apparatus is tested as each locomotive passes out of the shed yard by passage over a deliberately weak permanent magnet. The horn is set going and the driver must press the cancelling plunger before leaving on service.

We were particularly impressed with the robustness of the apparatus and the positive action obtained upon the receiver passing over the magnet poles — factors which augur well for the success of the equipment in all conditions of service. As there is no contact between the apparatus on the engine and that on the ground there can be no interference due to ice or heavy snow on the inductors.

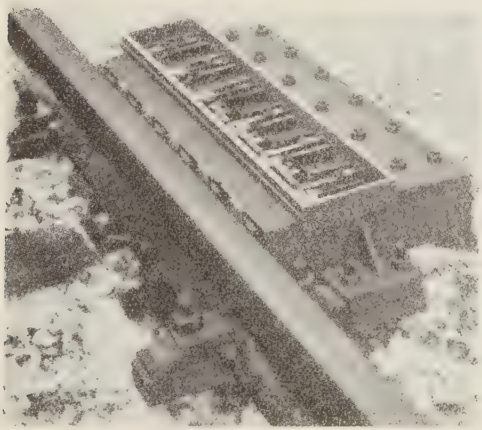
As announced previously, the London and North Eastern Railway Company, as a result of the experiments conducted over the last six years by the L.M.S., with which their officers have been in constant touch, have decided to install the Hudd system between Edinburgh and Glasgow.

[**625. 156** (.43) & **656. 259** (.43)]

3. — Signal innovation in Germany. — Wheel counting mechanism.

(*Modern Transport.*)

An interesting axle-counting mechanism has recently been introduced by the *Vereinigte Eisenbahn Signalwerke*. In the control of signalling the apparatus performs the same function as a track circuit. With reference to the diagram, it will be seen that the apparatus consists of a case (1) in which a series of powerful springs (2) is arranged in a row. The number of these springs varies according to the installation, so that variation is possible in the number of indications given by the apparatus . This is accomplished by having each spring control an electrical contact (6) through a pin (4), so that as the springs are lowered, the contact is closed. The number of springs, therefore, controls the number of electrical impulses sent out by each apparatus. To prevent mischievous operation the springs are designed to press against a bar (3) with sufficient force that the weight of a person standing on the projecting end of the spring is not sufficient to lower it.

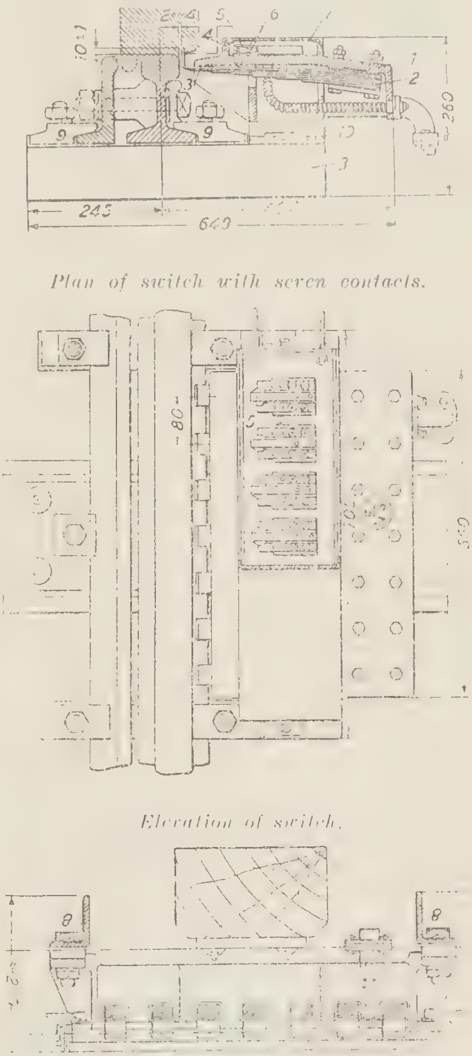


Method of attaching axle-counting device to a rail. In this picture the cover has been removed.

Cross section of switch.

Plan of switch with seven contacts.

Elevation of switch.



Arrangement of the new axle-counting device evolved in Germany.

The contact (6) is controlled by a small spring (5), which tends to keep the contact closed unless it is pushed up by the pin (4). The whole series of contacts and small springs are protected against weather by being enclosed in a weatherproof casing (7), which is shown with the cover removed in the accompanying illustration. The whole apparatus is installed on the outside of one of the rails of a track, and rests on two iron plates (8) fixed to the underside of the rail by clamps (9). Special plates (10) resting on the iron plates (8) are used to regulate the height of the apparatus so that the projecting end of the springs will be about 3/8 in. above the top of the rail head.

Method of operation.

When a train passes over the spot at which the switch is installed, the wheels press down the projecting ends of the springs (2), thus permitting the pin (4) to drop down so that the spring (5) can close the contacts (6). If all the contacts are connected in parallel, the apparatus will give only one single impulse, as the springs are sufficiently close together that before the one has time to open the contact it controls, the next one has already been opened. The length of time this impulse lasts will depend on the speed of the train. Only in the case of a very slow moving train will the apparatus send out a series of impulses.

By connecting the various springs in series or in series parallel, impulses with various characteristics peculiar to each individual switch can be obtained, these impulses acting on the signal equipment or current switches by means of ordinary relays of suitable characteristics, placed at any suitable point near the apparatus to be controlled. Moreover, by adding a counting relay to the circuit, to count the number of impulses (or series of impulses) the number of wheels in a train, hence its length, can be determined.

NEW BOOKS AND PUBLICATIONS.

[625. 144.2]

KNIGHT (P. E.), B. Sc., A. C. G. I., Engineer, Midland Uruguay and Associated Lines. — **String lining of curves.** — A volume (8 3/4 in. × 5 3/4 in.) of 118 pages, with 14 figures and appended tables. — 1938, London, *The Railway Gazette*, 33, Tothill Street, Westminster S.W. 1. (Price : 7 sh. 6 d. net).

The high speeds practised today and the growth of the rolling loads necessitate that curved track shall be laid in perfect alignment; irregularities in curve alignment give rise to shocks which are harmful to the permanent way, the rolling stock and the comfort of passengers, while they also diminish traffic safety.

On the other hand, however great the accuracy of the process employed in setting out a curve, both it and the adjoining portions of track become deformed after a certain time in service.

For this reason during recent years, both in America and Europe, methods of curve alignment have been developed on a large scale. The one explained in the book under consideration, written by Mr. P. E. KNIGHT, Engineer of the Midland Uruguay Railway and Associated Lines, is that known in America as the « Bartlett method ». The correcting process is based on principles similar to those described by Mr. J. CHAPPELLET in his book « Méthode de rectification du tracé des courbes de chemin de fer, par correction des flèches » (Method of rectifying the alignment of railway curves by correcting the versines).

We may briefly set forth these principles, so clearly explained by the engineer, Mr. POGNON.

« A circumference has this property that all arcs subtended by equal chords have equal versines. On the other hand, the parabolic transitions which connect the straight sections to the portion of the curve of constant radius are such that the versines of the arcs subtended by equal chords, increase at a constant rate from zero — which corresponds to straight track — up to the versine of the circular arc.

« There is thus a simple means of verifying the alignment of a curve, which is to plot its versines; any sudden variation in these will at once reveal an irregularity.

« To verify the alignment of a curve we are therefore led to measure its versines and compare them with those of another curve tangent to the same straight alignments and regarded as correct; then, to rectify the incorrect curve we have to displace it so that it occupies the position of the correct one.

« Consequently in order to define a method of verification and correction we have to investigate the relations existing between the versines measured on the curve concerned and those of a correct one and ascertain the displacement or slueing to be carried out at the various points of the existing curve to make it correspond with the correct alignment ».

Mr. Knight's treatment of the subject in English is remarkable for its simplicity and clearness. His book is also the object of a flattering preface by Mr. G. ELLSON, Chief Engineer, Southern Railway, whose authority on all permanent way matters is well known.

The explanations need only a knowledge of elementary mathematics to be understood.

Mr. KNIGHT has aimed at putting at the disposal of the junior staff precise instructions easily understood and applied, which are illustrated by clearly set out examples, while no complicated instruments, difficult to use in a hot climate, are needed, the versines being obtained with the aid of string.

There is an important chapter devoted to transition curves, and to superelevation; this part of the book contains interesting mathematical developments.

The setting out of the alignment selected is made the object of special instructions.

We may point out that Mr. KNIGHT is not an advocate of permanent monuments owing to the uncertainty of their remaining properly in place.

The book is neatly printed and of practical size, and is completed by a number of tables.

J. D.

[62. (01 & 621. 15 (0]

WILLIAMS (Fred. H.), M. Sc., F. R. S. A. — **Failures of locomotive parts and how to prevent them.** — One volume (11 in. × 8 3/4 in.) of 35 pages with 19 inset plates. Reproduced from the *Railway Mechanical Engineer.* (Price : 5 dollars.)

Mr. WILLIAMS has published during the last three years in the *Railway Mechanical Engineer* a series of articles on investigations, to which he has had occasion to devote himself, concerning the failures that have taken place with different parts of locomotives. These interesting contributions have just been issued in a single brochure with detachable leaves so that they can be completed by the chapters still to appear in the journal in question.

Long years of research, and analysis of the causes of the breakages of locomotive parts have enabled the author to arrive at the general conclusion that, although a certain number of failures may be due to the quality of the materials used or to various causes, such as defective application of processes like autogenous welding, etc., the greater number must be attributed to defective machining and finishing. He thus shows that the fact of neglecting certain details of finish which seem of small importance can lead rapidly to the breakage of parts. This is the case, for example, with coupling rods, in which the keyways have been finished off in a defective manner, or with tyres, which have not been bored satisfactorily, and with crank pins, where defective finish on the wheel fit has started incipient cracks, etc. The author analyses at length the cases of piston rod failure, connecting rod and axle breakages, and arrives at similar conclusions in these various cases : he points out what remedies are required, the shape to give to certain parts and the essential steps to be taken in finishing them so as to prevent a recurrence of the failures.

If some of these findings relate to practices not commonly met with in all countries, the deductions drawn from the interesting task to which the author has devoted himself, in the numerous cases he considers, will be a valuable help to the engineer who has to investigate such matters and enable him to discover the unsuspected causes of failures in certain parts of steam locomotives.

A. C.

[656. 225. 2]

PHEASANT (Howard E.), of the Buenos Ayres and Pacific Railway. — **Wagon Utilisation.** — A pamphlet (10 in. × 6 3/4 in.), 32 pages of text and 5 appended tables. — 1937, Buenos Ayres, The English Printery, B. Mitre 357.

This report was drawn up for submission to the June 1937 meeting of the Institute of Transport Argentine and River Plate Centre and deals with the distribution and control of ordinary and special type wagons, as well as the planning of wagon occupation, loading and movement.

The question is certainly one of considerable importance. The railways belonging to our Association asked that it be put on the agenda of the Cairo Session, 1933, where it was discussed at length. It came up again, at least as regards certain aspects of it, in the agenda for the 13th Session (Paris, 1937) where Question VIII was entitled : « Application of rational organisation (planning) to the transport of goods ».

Mr. Pheasant's report will be read with interest by all those professionnally concerned. He considers the subject as a whole, setting forth the methods used and the results obtained in Argentine, particularly on his own railway.

After an introduction in which he gives the rules applied in requesting and supplying empty wagons, loading, unloading, and dealing with time allowances for transport, he treats the subject in detail, in particular the allocation and control of the ordinary stock. Discussing special types of wagon, the author emphasises what he calls *complete control* and gives the noteworthy results obtained with the use of tank wagons, the necessary stock of which it has been possible to reduce.

Under the general title of wagon utilisation the author considers in turn : *the use of the stock,* which can be improved by various tariff and other measures, and the *wagon occupation* and *wagon loading,* in which rates again influence the matter concurrently with the steps taken to organise the traffic and, finally, the actual *wagon movement.*

The tables will be studied with attention by those departments concerned with the allocation of rolling stock. They illustrate the documents used on the author's railway and enable the reader to grasp the smallest detail of the work to be done by the stations and the various organisations concerned in the allocation of wagons.

E. M.

[656. 25 (.73)]

ASSOCIATION OF AMERICAN RAILROADS (A. A. R.), SIGNAL SECTION. — **American Railway Signaling Principles and Practices.** — Chapter XXIV : **Power Distribution Systems and Lightning Protection.** — A pamphlet (8 × 6 inches) of 34 + 12 pages, illustrated. — Published by the Signal Section of the A. A. R., 30, Vesey Street, New York, N. Y. — [Price : 30 cents (20 cents to members and railroad employees). Cost of the set of twenty-two chapters issued : 7 dollars (4.80 dollars to members and railroad employees). Binder to accommodate 13 chapters : 1 dollar. — Two binders will accommodate the whole series.]

The majority of the chapters of this noteworthy collection have been reviewed in these columns on their appearance. Our issue for October 1937, in particular, drew the attention of our readers to one of the most important, Chapter XXII, which deals with the block system.

The present one deals with power distribution systems, and their protection against accidental currents arising from atmospheric electricity. There is no need to dwell on the necessity of arriving at perfect continuity of supply, whether for power or lighting purposes, any interreuption producing troublesome repercussions on the working, especially since electric operation of apparatus has been extended to greater and greater distances. It is thus most useful to find, briefly exposed in a handbook, the essential rules to be observed in installing power lines.

Power systems for railway signalling purposes, have been designed for voltages of the following ranges :

second (over 30 to and including 175),

third (over 175 to and including 250),

fourth (over 250 to and including 660), and

fifth (over 660).

The most frequent use of these various systems and the power sources employed are briefly described, such as a commercial supply or an independent one, as well as the conditions under which they are installed on the telegraph and telephone pole line, on special supports, or on the catenary pylons of electric railways. In other circumstances underground cables are used.

Diagrams are given showing the principal details of mounting the equipment, with sectionalizing switches and, when required, transformers. Capacitors are sometimes used to improve the power factor.

Protection against electrical atmospheric disturbances has been the object of intensive investigation and a special committee has drawn up a specification bearing the number 52, and entitled : *Low voltage lightning arrester*, the text of which is reproduced in full, followed by particulars and drawings of various types, the efficiency of which has been proved by experience.

The work is concluded with the usual questionnaire, bringing out the principal points to be remembered by the staff called on to maintain electric signalling installations.

E. M.